EFFECT OF SWIM TRAINING ON PHYSICAL CHARACTERISTICS AND PAIN IN COMPETITIVE ADOLESCENT SWIMMERS

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ABSTRACT

ELIZABETH E. HIBBERD: Effect of Swim Training on Physical Characteristics and Pain in Competitive Adolescent Swimmers
(Under the direction of Joseph B. Myers)

The purpose of this research study was to determine the effect of swim training on physical characteristics, such as range of motion, posture, pectoralis minor length, and subacromial space distance, and pain and functional scales in competitive adolescent swimmers. Our secondary objective was to determine the effect of training load on changes in these physical characteristics and pain scores. Our approach was to recruit 45 competitive adolescent swimmer and 31 non-overhead athletes. Participants had a physical exam completed by the research team to measure the physical characteristics of interest at 3 time points during the season (preseason, 6-weeks into the season, and 12-weeks into the season). There were no clinically significant differences in swimmers and non-overhead athletes on posture, normalized pectoralis minor length, normalized subacromial space distance, and ROM variables. Swimmers presented with significantly more posterior shoulder tightness than non-overhead athletes. These findings indicate that factors other than swimming participation, such as school and technology use, play an important role in the adaptation of physical characteristics. Due to the training load, swimmers experience a decrease in subacromial space distance and external rotation range of motion and an increase in forward shoulder posture over the course of the training

season when compared to non-overhead athletes. These adaptations may increase the risk of shoulder pain and injury in competitive swimmers. Over the course of the training season, a high percentage of swimmers reported pain with moderate disability and significant relationships were observed between total yardage performed and PENN and SPADI scores, which indicate training volume is a contributor to the development of shoulder pain and disability. The significant changes in the physical characteristics that are seen in competitive swimmers during the training season compared with changes in non-overhead athletes and the relationships between total yardage and pain scores indicate that the training season clearly has a substantial influence on physical characteristics that may lead to shoulder pain and injury.

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INTRODUCTION

1.1 Swimming Participation

Swimming is a popular sport in the United States with a growing number of athletes that participate annually. It has been estimated that over 120 million individuals swim recreationally, with an additional 5 million individuals competing on high school teams, 301,000 members of USA Swimming competing on club teams, 60,000 US Masters Swimming members, and 22,000 NCAA swimmers who swim in competitive leagues.[1-4] Within the group of competitive club swimmers, 43.5% of the members are between the ages of 13-18 and are competing on elite teams, with tremendous demands on training.[3] Club swimmers between the ages of 13-18 have previously been reported to complete approximately seven practices per week with average practice yardage of 6,000-7,000 yards per practice for approximately 11 months out of the year.[5]

1.2 Swimming Related Injury Epidemiology and Etiology

Due to these high levels of training, it is hypothesized that physical characteristics of swimmers' upper extremities adapt to the demands that are placed on them and predispose them to "swimmer's shoulder," which is the general term for overuse injury in swimming athletes.[6-8] "Swimmer's shoulder" is commonplace in swimming, as at least 55% of all injuries in competitive swimmers affect the shoulder.[9] Further, interfering shoulder pain has been reported in 45-87% of swimmers during their careers.[10-12] In competitive youth swimmers, 85% of swimmers believe that mild shoulder pain is normal and should be tolerated in order to complete the necessary yardage, with 72% of the swimmers reporting use of pain medication (either prescribed or over-the-counter) in order to participate.[5] The prevalence of shoulder injuries and the beliefs regarding shoulder pain in youth swimmers highlight the need for an effective assessment tool and intervention program to be validated for youth swimmers.

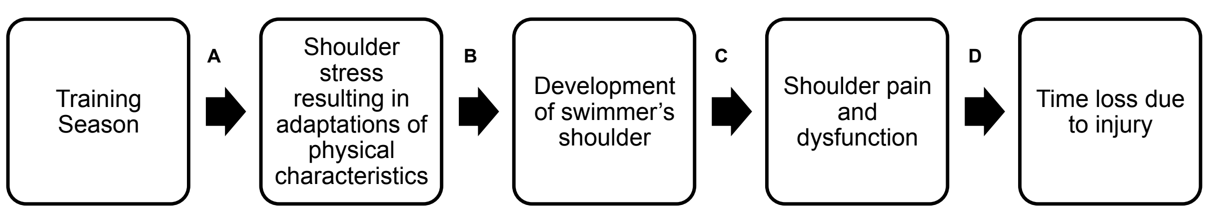
While the exact cause of “swimmer’s shoulder” and the associated pain is unknown, several theories have been hypothesized including decreased subacromial space distance, altered scapular kinematics, altered muscle recruitment pattern, posterior shoulder tightness, humeral head displacement and altered physical characteristics.[13-24] Identifying adaptations of physical characteristics and risk factors of “swimmer’s shoulder” is imperative in order to understand how participation affects the potential risk factors and to accomplish our ultimate goal of preventing shoulder injuries in competitive swimmers.

As previously established, competitive club swimming is a year round sport with very limited time for rest and recovery.[5,8] The competitive swimming season is broken into a cardiovascular/endurance phase that occurs in the training season and a taper period that occurs in the competition season.[25] During the training season, competitive swimmers perform a large volume of yardage with high intensity practices in order to gain strength and power.[26] As the competition season approaches, swimmers begin to taper, which allows for muscle recovery and rest, ultimately optimizing physiological and psychological components to maximize performance in competitions.[27,28] Typically, swimmers train and taper for two major meets during the year, taking a few weeks off between their competition and the time when they start their training again.

Clinically, athletic trainers treat a high percentage of athletes reporting for treatment of shoulder pain during the training season. Due to the high training load, it is hypothesized that physical characteristics of swimmers change due to participation factors and predispose the athlete to shoulder pain and injury.[8] Swimmers have previously been described as having increased external rotation, while demonstrating less internal rotation range of motion when compared to normalized data in controls.[6] Altered range of motion in swimmers may predispose swimmers to injuries by altering scapular kinematics and causing abnormal stress on the surrounding musculature.[6,11] Swimmers have also been found to have increased shoulder internal rotation and adduction strength, due to adaptation from the demands of the sport.[6,11,29]. As a result, imbalances are created in the internal rotation/external rotation ratio and the abduction/adduction ratio which has been found to lead to pain.[30] Swimmers typically demonstrate altered posture with forward head, rounded shoulders, and increased thoracic kyphosis, which can affect scapular kinematics, muscle strength, and range of motion.[31-33] Finally, subacromial space distance[34-39] and supraspinatus tendon thickness[39] are two hypothesized risk factors for the development of overuse injury in competitive swimmers. These are the proposed risk factors in physical characteristics that may contribute to the development of “swimmer’s shoulder”.

Theoretically **(Figure 1)**, large amounts of swim training would result in increased stress on the shoulder and manifests as adaptations in physical characteristics that may predispose the athlete to injury **(Line A)**. These identified intrinsic and extrinsic factors may predispose the athlete to the development of swimmer's shoulder **(Line B)** causing shoulder pain and dysfunction **(Line C)** and ultimately resulting in time loss due to injury **(Line D).** These alterations are hypothesized to develop due to the training load, but research is needed to determine the effect of swim training on these physical characteristics that may be causative of impingement and the development of swimmer's shoulder. Identifying how these physical characteristics change due to swim training, allowed for the development of better injury prevention programs that address the specific physical characteristics that are changing due to training. Further, measuring over the course of the training season allowed us to determine the appropriate time to intervene. Moreover, focusing on a youth swimming population will help to identify the effects of participation and alterations in physical characteristics that occur early in an athlete's career and potentially prevent shoulder pain from affecting the entire career of the athlete.

Figure 1: Theoretical Model of the Development of Shoulder Pain and Injury



1.3 Statement of Purpose

Although previous literature has suggested that shoulder physical characteristics change with high loads of swimming, a prospective evaluation of these characteristics is necessary to determine if they truly are affected by swimming participation. *Therefore, the purpose of this project is to prospectively identify the effect of the training season on physical characteristics and shoulder pain and the relationship between participation factors and each of the physical characteristic variables in competitive youth swimmers.* Evaluating these changes in the physical characteristics in competitive swimmers and their relationship to participation variables will advance the understanding of the effects of swim training on physical characteristics and provide support for future studies focusing on injury prevention programs and practice recommendations. In addition, evaluating how the physical characteristics change during the training season and their relationship with shoulder pain/functional scales and cumulative yardage, a screening tool can be developed to identify at risk individuals as well as provide information regarding the development of intervention programs and practice guidelines for competitive swimmers.

1.4 Operational Definitions

- **Shoulder Physical Characteristics:** Selected measurable shoulder physical characteristics that are used to develop a profile of a swimmer. These shoulder physical characteristics include: glenohumeral range of motion, standing posture, pectoralis minor length, and subacromial space distance.

- **Competitive Club Swimmers**: Swimmers between the ages of 13-18 that are competing on club teams at the top training level for their specific club
- **Training Season**: The first 12 weeks of the swimming periodization training cycle in which the focus is on the development of cardiovascular endurance.

1.5 Specific Aims

Specific Aim 1

To determine the effect of the training season on physical characteristics (glenohumeral range of motion, posture, pectoralis minor length, subacromial space distance, and pain/functional scales) in competitive club swimmers.

> ***Hypothesis 1*:** The shoulder physical characteristics of youth swimmers will adapt over the course of the training season to a shoulder profile that predisposes that athlete to injury. Specifically, following the training season, the swimmer will present with at least one of the following alterations in physical characteristics: **decreased glenohumeral range of motion** (internal rotation, external rotation, horizontal adduction), **increased forward head and forward shoulder posture**, **decreased pectoralis minor length**, **decreased subacromial space distance**, **increased pain scores and decreased functional scores**.

Specific Aim 2

To determine the relationship between 6-week training volume and total yardage to changes in physical characteristics in competitive youth swimmers.

Hypothesis 2: There were **a direct positive relationship between (a) 6-week training volume and changes in physical characteristics and (b) total yardage and changes in physical characteristics** in youth competitive swimmers following the training season.

1.6 Independent Variables

Specific Aim 1

- Time (pre, 6-weeks, 12-weeks)
- Group (swimming/control)

Specific Aim 2

- Participation Factors (Cumulative yards, average yards/practice)

1. 7 Dependent Variables

Specific Aim 1

- Range of Motion (Internal Rotation, External Rotation, Horizontal Adduction)
- Posture (Forward Head and Forward Shoulder Angle)
- Normalized Pectoralis Minor Length
- Subacromial Space distance
- Pain/Functional Scales

Specific Aim 2

- Range of Motion (Internal Rotation, External Rotation, Horizontal Adduction) Change Score
- Posture (Forward Head and Forward Shoulder Angle) Change Score
- Normalized Pectoralis Minor Length Change Score

- Subacromial Space distance Change Score
- Pain/Functional Scales Change Score

1.8 Limitations

- Recording of daily training were reported by coaches and swimmers and not measured directly by the research team.
- The effort that each participant puts into the training cannot be assessed.
- Activities outside of team training cannot be controlled.
- An individual may inadvertently correct their "normal" posture during measurements if they know they are being tested for posture.
- The 2D US measurements of subacromial space cannot capture the effects on subacromial space during normal 3D shoulder movement.

1.9 Delimitations

- Only youth club swimmers from North Carolina were included.
- Only members of the top training level of each team were included.

1.10 Assumptions

- Participants assumed natural, normal upright posture when measurements are taken
- Youth swimmers used in this research study are representative of other youth swimmers
- Training volume/training intensity of youth swimmers within North Carolina reflects training volume/training intensity of other competitive club swim programs.

CHAPTER II

REVIEW OF LITERATURE

2.1 An Overview

Swimming is a popular sport in the United States with a growing number of athletes that participate annually. It has been estimated that over 120 million individuals swim recreationally, with an additional 5 million individuals competing on high school teams, 301,000 members of USA Swimming competing on club teams, 60,000 US Masters Swimming members, and 22,000 NCAA swimmers who swim in competitive leagues.[1-4] Within this group of competitive club swimmers, 43.5% of the members are between the ages of 13-18 and are competing on elite teams, with tremendous training demands.[3] These club swimmers are exposed to tremendous training loads, performing between 42,000-49,000 yards per week (over approximately 7 practices) in addition to dry-land training and weight training.[5] Previous studies have indicated that swimmers take an average of 15 strokes per 25 yards,[40] which would indicate that these club swimmers experience 25,200-29,400 shoulder revolutions per week while completing their swim training. The number of shoulder revolutions compares with 1000 revolutions per week in a professional tennis player or baseball pitcher and 300 shoulder revolutions per week in a college javelin thrower.[10] Due to this tremendous training load, shoulder pain is the most common musculoskeletal pathology that in competitive swimmers.[41-45]

2.2 Swimming Related Injury Epidemiology

Repetitive microtrauma due to high volume swim training may lead to shoulder pain and injury in competitive swimmers. Shoulder injury rates in competitive swimmers have been previously reported as 0.2 to 0.3 injuries per 1,000km,[46] indicating the influence of volume of training on shoulder injury rates. Interfering shoulder pain has been reported in 45-91% of swimmers during their careers.[8,10-12] Shoulder pain in swimming is a major cause of missed practice and slower swim times[41] and may develop as a result of the fact that 90% of propulsive force in swimming comes from the upper extremity because the athlete must pull the body over the arm through the water.[12]

Anecdotal evidence suggests that the culture of swimming dictates that shoulder pain is normal for competitive swimmers and it should be tolerated if they want to succeed. Eighty-five percent of youth/adolescent swimmers believe that mild shoulder pain is normal and should be tolerated in order to complete the necessary yardage, with 72% of the swimmers reporting use of pain medication (either prescribed or over-the-counter) in order to participate.[5] The prevalence of shoulder injuries and the beliefs regarding shoulder pain in youth swimmers highlight the need for an effective assessment tool and intervention program to be validated for youth swimmers. While many athletes believe they should participate despite pain, it has been well established in the literature that pain alters motor control strategies and may contribute to neuromuscular adaptations, increasing the risk of injury development.[47] Specific to the shoulder, kinesthetic deficits have been found in the dominant limb of baseball pitchers who reported pain, despite not being diagnosed with a specific injury.[48] Further, it has been suggested that alterations in muscle firing patterns and inhibition of scapular stabilizing muscles due to shoulder pain may be a cause of scapular dyskinesia, which has been suggested as a risk factor for injury.[49,50] In swimming, previous literature has identified that individuals who reported pain had alterations in neck, scapular stabilizing and shoulder musculature that may contribute to decreased performance and increase the risk for the development of swimmer's shoulder.[51,52]

2.3 Etiology of Swimmer's Shoulder

The high volume of swim training is hypothesized to contribute to alterations in the physical characteristics as the shoulder adapts to the demands that are placed on it and predispose them to the development of "swimmer's shoulder," which is the general term for overuse injury in swimming athletes.[6-8] Swimmer's shoulder was originally defined as anterior shoulder pain during and after swimming that was caused by subacromial impingement of the rotator cuff tendons in the coracoacromial arch.[12,53] As more research was conducted in the area of shoulder injuries in swimmers, this definition has been modified and swimmer's shoulder is now a general term for a shoulder overuse injury and pain in swimmers, which encompasses subacromial impingement, rotator tendinosis, and biceps tendinosis.[6,7,54] Each of these injuries is discussed in greater detail below.

Subacromial Impingement

Subacromial impingement is also commonly called external impingement and is a mechanical compression of the rotator cuff tendons, biceps tendon, or subacromial bursa by the acromion, which causes pain, loss of range of motion and decreased strength and functioning.[55] The coracoacromial arch is made of the anterior acromion, coracoacromial ligament and the humeral head. In shoulder impingement syndrome, the contents within the subacromial space, the area beneath the coracoacromial arch, become compressed.[17,56] The contents of the subacromial space include: the supraspinatus, long head of the biceps and the subacromial bursa. The other rotator cuff muscles, the infraspinatus, teres minor and subscapularis, are also susceptible to being impinged between the humeral head and the undersurface of the acromion as they become confluent with the glenohumeral capsule.[57,58] Compression of any of these structures may lead to pain and dysfunction, especially in an overhead athlete.[17,56,58-60]

Subacromial impingement can be classified as primary or secondary impingement.[55,56,60] Primary external impingement is the irritation of the rotator cuff due to mechanical narrowing of the subacromial space due to subacromial spurring or an altered shape of the acromion.[55,61] These bony deformities affect the amount of space available in the subacromial space and increase the incidence of impingement.[62,63]

Secondary subacromial impingement is when the subacromial structures become compressed as a result of functional narrowing of the subacromial space.[64] As shoulder movement occurs, the size of the subacromial space changes. During movement, the humeral head narrows the subacromial space leading to increased compression of the structures within the subacromial space.[14,17,60] Functional narrowing of the subacromial space can occur due to weak rotator cuff and scapular stabilizing muscles,[14,17,65,66] altered scapular kinematics due to weak scapular stabilizing musculature,[18,19,67-69] abnormal posture,[31] and posterior shoulder tightness.[20,70]

These are some of the hypothesized causes of subacromial impingement. Due to specific physical characteristics of swimmers and a combination of these theories, subacromial impingement is the most common injury diagnosed in swimmers.[71] This multifactorial diagnosis is a major contributor to shoulder pain.

Rotator Cuff Tendinosis

Rotator cuff tendinosis is a chronic intratendonous disease that includes chronic inflammation, degeneration, or tearing in the rotator cuff.[59] Degeneration of the rotator cuff tendons occur most often in overhead sports due to the repetitive impingement and resultant microtrauma from the movements of the shoulder during athletic activity.[72] Rotator cuff tendinosis can result from primary or secondary impingement. Hooked acromions, os acromiale, and acromiclavicular osteophytes have all been suggested as possible causes of primary impingement leading to rotator cuff injury and degeneration.[73-75] Rotator cuff tendinosis due to secondary impingement can occur due to any of the previously discussed risk factors for subacromial impingement, such as weak rotator cuff musculature,[14,17,65,66] altered scapular kinematics due to weak scapular stabilizing musculature,[18,19,67-69] abnormal posture,[31] and posterior shoulder tightness.[20,70] Rotator cuff tendinosis has been found to be more common in overhead athletes with improper functioning of the scapula.[76] These risk factors cause functional narrowing of the subacromial space resulting in increased mechanical compression on the structures of the within the subacromial space, particularly the rotator cuff tendon. In addition to risk factors from impingement, overuse has been proposed to be a risk factor for the development of rotator cuff tendinosis.[77] Due to impingement that occurs during the repetitive overhead motions of swimming, microscopic failure of the fibrils within the tendons occurs and can lead to tendon injury and degeneration.[78] In rats, tendon injuries have been shown to develop due to alterations in the supraspinatus tendon from overuse.[77,79] Swimmers are particularly vulnerable to the development of rotator cuff tendinosis due to their training demands, paired with alterations in physical characteristics that cause subacromial impingement.

Individuals with rotator cuff tendinosis often experience a deep, achy pain that becomes worse as the arm is elevated. Rotator cuff tendinosis is typically treated non-operatively to start, with rest, pain management using NSAIDs, strengthening and ROM exercises, and activity modification.[80] Surgery for rotator cuff tendinosis is usually done after 6-18 months of failed conservative treatment for individuals with partial or complete rotator cuff tears.[56,81]

Biceps Tendinosis

The long head of the biceps is particularly vulnerable to injury from impingement due to its location in the subacromial space, specifically the rotator interval.[82] The rotator interval is the triangular space that is located between the supraspinatus and subscapularis tendons and contains the biceps tendon as it crosses the shoulder joint obliquely from the supraglenoid tubercle and glenoid labrum, through the bicipital groove, to the radial tuberosity.[82-84] The rotator interval is essential to maintaining correct positioning of the biceps tendon.[85] The function of the long head of the biceps has often been debated and has been hypothesized to function as a humeral head depressor[86-88], anterior stabilizer[89-93], posterior stabilizer[94], or to have no active role at the glenohumeral joint.[95]

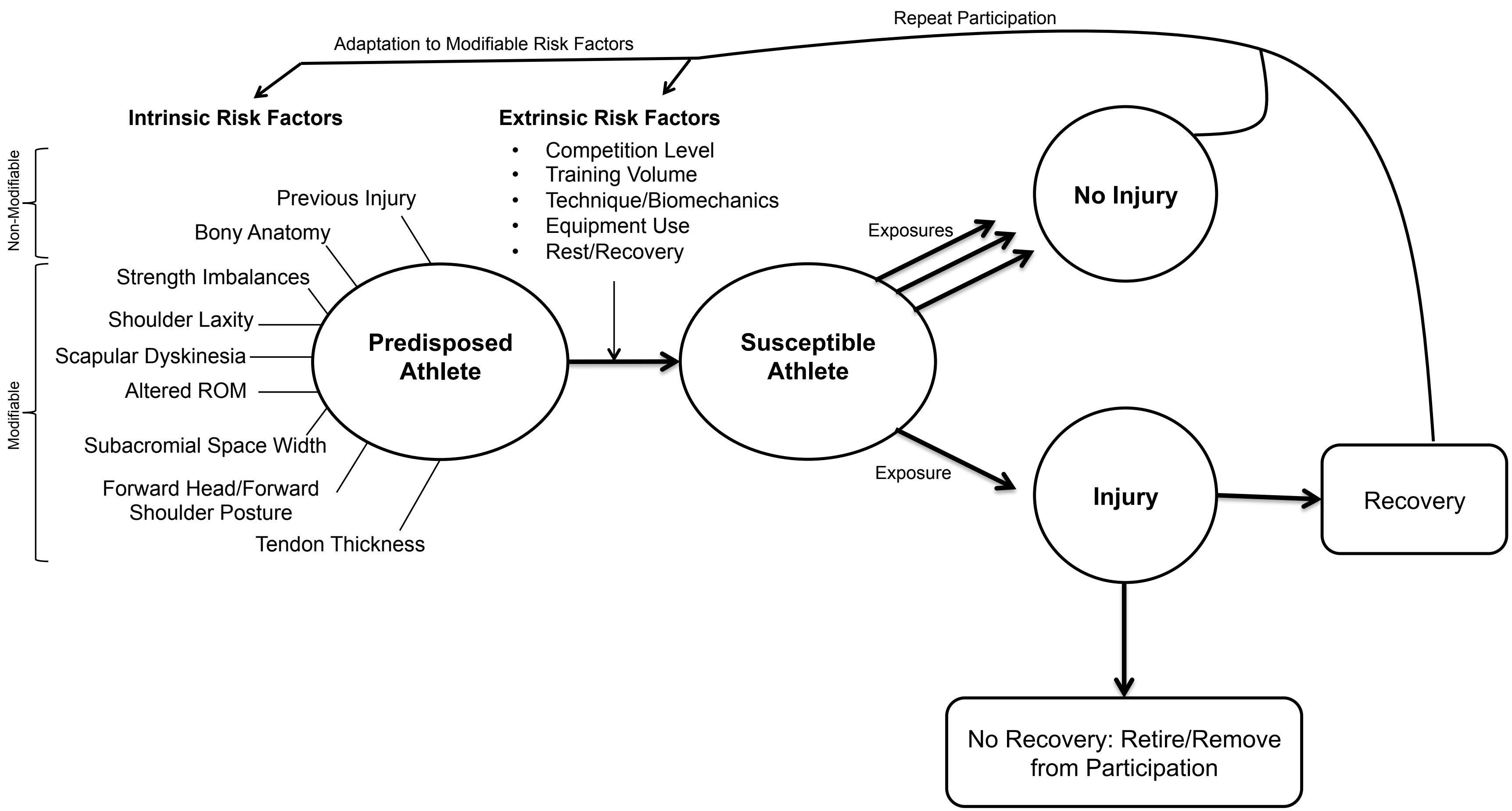
Regardless of the function of the long head of the biceps brachii at the glenohumeral joint, it is vulnerable to injury due to its location within the subacromial space through the rotator interval. Biceps tendinosis is an overuse injury that occurs in overhead athletes due to the repetitive nature of the sport and can be classified as inflammatory/degenerative condition. Degeneration of the biceps tendon has been proposed to be due to mechanical irritation of the biceps tendon against the coracoacromial arch as it runs through the rotator interval.[96] Previous research has determined that shoulder flexion and adduction causes anterior and superior migration of the humeral head, which causes a decrease in subacromial space and thus increases the risk of mechanical compression of the structures with in the subacromial space, including the long head of the biceps.[70] Flexion and adduction are movements that are associated with entry and pull through phase of the swimming stroke, which are also phases where previous research has identified impingement occurring.[97] Due to the biomechanics of the swimming stroke and volume of repetition, these athletes may be at increased risk for the development of biceps tendinosis. In addition to stroke characteristics, individuals with a tight posterior capsule[70] or muscles weakness[98] may have even greater humeral head superior migration, furthering their risk of developing biceps tendinosis. Overhead athletes are particularly vulnerable to the development of biceps tendinosis secondary to primary impingement.[99]

Individuals with biceps tendinosis will have localized tenderness, crepitus, swelling and potential tissue damage of the biceps tendon, which will cause pain with overhead activities.[100] Effective treatment is based on first determining the primary cause of the injury. As previously discussed, there can be a variety of causes of biceps tendinosis and determining the specific cause is imperative to guide treatment. Conservative rehabilitation of rest, NSAIDs and strengthening is typically successful.[100] If conservative treatment is not successful, surgery may be necessary for the young athlete to return to their desired level of functioning.[95,101]

2.4 Risk Factors for Shoulder Injuries in Competitive Swimmers

The development of shoulder pain and injury in swimmers is multifactorial due to a combination of both intrinsic and extrinsic risk factors. With the presence of modifiable and non-modifiable intrinsic risk factor, the individual may be predisposed to the development of shoulder pain and injury. With the presence of extrinsic risk factors, the athlete is susceptible to the development of shoulder pain and injury. Through repeated exposures, without the presence of a diagnosed injury, the modifiable intrinsic risk factors that swimmers are exposed to are continually changing due to adaptations of the shoulder during swim training. In some cases, due to a combination of these intrinsic and extrinsic factors, the susceptible athlete will develop an injury that will either lead to recovery, with associated adaptations in the modifiable intrinsic risk factors, or pain/injury that the athlete is unable to recover from leading to voluntary retirement by the athlete or removal from participation by the medical personal. This model has been adapted from the Meeuwisse dynamic, recursive model of etiology of sport injury[102] to be specific to the risk factors in competitive swimmers and is diagramed in **Figure 2.**

Figure 2: Theoretical Risk Factors For the Development of Swimmer's Shoulder



Non-Modifiable Intrinsic Risk Factors

There are several non-modifiable intrinsic risk factors for the development of swimmer's shoulder. These include: competition level, previous injury, and acromion shape.

Participation Factors

There are several participation factors that increase the risk of a swimmer developing shoulder pain and injury. Previous research has identified that the earlier a swimmer begins participation in the sport, the greater the risk of development of swimmer's shoulder.[103,104] Because of the training demands and time expectations of youth swimmers, swimming is traditionally a sport of early specialization, where athletes focus solely on swimming.[105] In a 10-15 year swimming career, competitive swimmers will only have 1-2 months of unscheduled practice time per year, resulting in significant exposure to the stresses of the swimming stroke which may cause adaptations of physical characteristics that increase the risk of injury.[11,40] In addition to age of specialization, the level of competition is also one of the greatest risk factors for the development of injury.[8,46,104] As competition level increases, so do the number of practice sessions and yards per session. The increasing volume of swimming that comes with increased competition level has been associated with alterations in physical characteristics and shoulder pain.[8,46,104] Previous history of a shoulder injury is also a risk factor for the development of future incidences of swimmer's shoulder.[46,104] Athletes may not fully address the physical characteristics or abnormal biomechanics that contributed to the development of the initial injury, rather simply taking time off until pain decreased. Without addressing these initial causes of the injury, the swimmer may be caught in a perpetual pain cycle.

Acromion Morphology

In addition to participation factors, acromion morphology is an anatomical factor that is non-modifiable and contributes to the development of shoulder injury. There are three types of acromion shape that have been identified in the literature. A type 1 acromion is flat and has a low incidence of impingement, type 2 is curved and has a greater incidence of impingement and type 3 is hooked and has the highest incidence of impingement.[62,63,106] These bony deformities, particularly the type 3 (hooked) acromion, decrease the amount of space available and can increase the amount of compression on the tissues of the subacromial space.[62,63] Throughout glenohumeral range of motion, individuals with a hooked acromion experience greater contact of the acromion with the tendons of the rotator cuff.[107] Due to increased contact of the rotator cuff tendons with the acromion, rotator cuff pathology is likely to develop.[62] Hooked acromions are more prevalent in patients with impingement than in healthy individuals[108] and in individuals with rotator cuff tearing, with tearing of the rotator cuff present in up to 89% of individuals with a type 3 acromion.[73,108,109]

In addition to acromion type as a contributor to primary external impingement, many clinicians have identified the presence of inferiorly protruding osteophytes from the anterior aspect of the acromion and inferior aspect of the AC joint, which may compromise the integrity of the rotator cuff tendons as they pass below these structures.[75] Further, the traction spurs that develop at the anterior bony prominence are indicative of an enthesopathic reaction caused by the humerus repeatedly abutting the undersurface of the coracoacromial arch. Chambler et al[110] has suggested that humeral contact from the overhead motion causes rapid changes within the substance of the coracoacromial ligament that provoke adaptive changes at the enthesis, leading to spur formation. Tendon degeneration occurs as the rotator cuff becomes frayed or irritated. Radiological examination is necessary to confirm the diagnosis of primary external impingement. Treatment of primary external impingement is typically surgical before the weaknesses and decreased range of motion of the rotator cuff can be addressed.

Modifiable Intrinsic Risk Factors

Strength Imbalances

The upper extremity, primarily the shoulder, is responsible for forward propulsion during swimming.[10] Significant shoulder strength is necessary to propel the body through the water. A direct relationship has been found between shoulder strength and swimming speed.[111] Shoulder adduction and elbow extension is the primary movement required to produce the force necessary to move the body during swimming. These movements are produced mostly by the pectoralis major, latissimus dorsi, and triceps brachii.[6] Because of the contribution from the pectoralis major and latissimus dorsi muscles, swimmers tend to have increased internal rotation and adduction strength.[11,42,112] In the typical population, the conventional concentric external rotation (ER) to concentric internal rotation (IR) strength ratio is .75, while swimmers have a significantly lower ratio at .64 due to the increased internal rotation strength.[6,11] A functional ER:IR strength ratio has been used to compare eccentric external rotational strength and concentric internal rotational strength in order to compare the strength differences during ballistic overhead activity and has been found to be predictive of injury in swimmers.[6] The functional ER:IR strength ratio may be a more appropriate measure of muscular imbalance, as it measures the external rotators eccentric ability to decelerate the humerus to center the humeral head while the internal rotators are forcefully contracting concentrically, a movement that is common in swimming and all overhead sports. A significant increase in the functional ER:IR ratio on the symptomatic side compared to the asymptomatic side, as well as between painful and non-painful groups has been observed in Danish National Swimmers.[6] This finding indicates that concentric internal rotation strength may be decreased in swimmers who are experiencing shoulder pain. Therefore, rehabilitation and prevention programs need to incorporate exercises that focus on internal rotation strengthening as well as external rotation strengthening, in order to address the needs of the athlete.

Competitive swimmers have organized practice for 10-12 months out of the year with 7-12 practices a week, which can greatly affect the athletes' muscular strength throughout the course of a season.[11] Ramsi et al[113] studied the shoulder rotator strength of high school swimmers over the course of a competitive season. Twenty-seven high school varsity swimmers internal and external strength was measured preseason, midseason, and postseason to detect changes. Internal and external rotation strength significantly increased throughout the season, although internal rotation strength gains were significantly more than the external rotation strength gains, decreasing the functional ER:IR ratio, which has been found to lead to pain in swimmers, and indicates that swimmers may be further predisposed to injury later in the season as the strength gains occur disproportionately.[6,113]

The rotator cuff muscles serve to compress the humeral head dynamically into the glenoid, providing stability during motion of the glenohumeral joint. If the rotator cuff muscles are weak or fail to stabilize the humeral head in the glenoid, impingement may be seen during overhead movement. The action of the deltoid muscle will not be counterbalanced and the humeral head may translate superiorly into the coracoacromial arch, compressing the structures in the subacromial space. Myers et al[114] found that participants with subacromial impingement have increased middle deltoid activity at the initiation of shoulder elevation. This occurs at a position where the tendency for superior migration of the humeral head into the subacromial space is high.[115] In addition, the authors found decreased co-activation ratios between the subscapularis-infraspinatus, supraspinatus-infraspinatus, and subscapularis-supraspinatus at the initiation of elevation in the subacromial impingement patients due to decreased overall mean activation of the dynamic stabilizers. Together, these findings suggest that the tendency for increased humeral head superior migration is attributable to increased deltoid activation and a compromised ability to oppose this migration due to decreased co-activation. The encroachment of the subacromial structures and resulting pain that occurs during the painful arc associated with subacromial impingement may be attributed to these muscle activation alterations that are occurring. In addition to superior migration of the humeral head, muscular imbalances alter the stability of the shoulder, by changing the vectors of pull. The altered vector of pulls results in shoulder instability because of decreased compressive forces on the humerus, which helps to center the humeral head.[116] Shoulder instability can lead to pain, impingement and decreased functioning in overhead athletes.[24,116,117]

The repetitive nature of swimming may cause fatigue of the posterior rotator cuff muscles, which may place more stress on the posterior capsule to maintain joint stability through the swimming stroke.[118] It is believed that with time, this increased distractive stress will cause repetitive microtrauma to the posterior capsule and a fibroblastic healing response resulting in hypertrophy and contracture. This tight and hypertrophied posterior capsule causes a shift in the arthrokinematics of the glenohumeral joint. Tightness of the posterior capsule, which is known to limit glenohumeral internal rotation, creates an obligate anterior and superior humeral translation during flexion.[20,70] As athletes with posterior shoulder tightness move into the flexion with external rotation (as seen in the recovery phase of the swimming stroke), there is increased superior-posterior translation of the humeral head.[119-121] These abnormal translations can decrease the acromiohumeral distance and compress the structures within the subacromial space.

Shoulder Laxity

The anterior capsule undergoes significant tensile stress during the swimming motion, particularly in the finish and recovery phases of the swimming stroke.[7,122] This stress can lead to gradual stretching of the capsular collagen and over time leads to increased anterior capsular laxity. This repetitive strain on the anterior capsule causes anterior capsular laxity over time.[123] It has been demonstrated in cadavers that excessive external rotation results in elongation of the anterior band of the inferior glenohumeral ligament complex, resulting in a significant increase in anterior and inferior capsular translation.[124] This indicates that swimmers may develop laxity from their repetitive strokes that may manifest as anterior instability or microinstability, allowing the humeral head to translate anteriorly during the finish and recovery phases and causing the posterior rotator cuff musculature to be impinged on the posterosuperior glenoid rim.

Many studies have aimed to find the effect of shoulder instability on muscle activation patterns. Illyés and Kiss[125] found that subjects with multidirectional instability had decreased time of activation of all three portions of the deltoid muscle and pectoralis major during an elevation task compared to controls. In order to compensate for the shorter activation of these muscles, the supraspinatus, infraspinatus, biceps brachii, and triceps brachii have longer activation times. The authors of this study suggest that the shorter activation times of the deltoid and pectoralis major and longer activation times of the other muscles in individuals with multidirectional instability occurs in order to centralize the humeral head in the glenoid fossa. While the humeral head may be centered, these altered patterns of activation significantly affect the scapular kinematics in individuals with multidirectional instability and yield a greater humeral head displacement compared with controls during an elevation task.[125]

Scapular Dyskinesia

Altered patterns of scapular kinematics have also been shown to be associated with the development of subacromial impingement. The scapula is the cornerstone of upper extremity movement and its primary role is to ensure proper position and motion for optimal shoulder function.[126] In an asymptomatic individual, upward rotation, posterior tipping and decreased internal rotation, retraction, and elevation is the common movement pattern as the humeral angle increases.[15,127] Upward rotation of the scapula serves to elevate the lateral acromion in order to prevent impingement and is the primary scapular motion.[67] Posterior tipping of the scapula is a secondary scapular motion and moves the anterior acromion posteriorly in order to prevent impingement of the rotator cuff tendons.[67] External rotation moves the acromion posteriorly to decrease contact with the rotator cuff tendons.[67]

Normal movements of the scapula have been found to be altered in individuals who present with shoulder pain. Several studies have shown alterations in scapular kinematics with the presence of impingement syndrome.[18,19,67,68] In a study by Ludewig and Cook,[19] subjects with impingement syndrome were found to have decreased upward rotation, decreased posterior tilt and an increase in internal rotation between symptomatic and asymptomatic individuals. Myers et al[128] found that throwing athletes presented with increased upward rotation, internal rotation, and retraction of the scapular during humeral elevation tasks when compared with non-throwing athletes. The authors hypothesized that these alterations were due to chronic adaptation from the throwing motion. Although these alterations have been found to be associated with subacromial impingement, Oyama et al[129] found that alterations in 3-D kinematics in baseball players were present even in the asymptomatic athlete, indicating that these adaptations occur from repetitive overhand activity. These alterations in normal scapular kinematics in throwers may also be occurring in swimmers due to the repetitive motion of the swimming stroke. These findings are important in understanding scapular kinematics in overhead athletes that may be injurious, as normal scapular kinematics in overhead athletes may already have alterations that could predispose them to injury. Any subsequent alterations in scapular kinematics, such as weak or altered activation patterns, tightness of the pectoralis minor and major, or tight posterior shoulder lead to further scapular protraction, anterior tilting, and downward rotation, which causes the scapula to tilt downward and places the acromion in a more horizontal position.[126,130] This, in effect, lowers the roof of the coracoacromial arch and provides mechanical compression to the tissues in the subacromial space.[13]

Scapular positioning can also be affected by decreased glenohumeral internal rotation range of motion. It has been shown that individuals with glenohumeral internal rotation deficit (GIRD) of greater than 15° on the dominant side compared to the non-dominant have significantly less scapular upward rotation,[69] decreasing the amount of space between the lateral acromion and subacromial structures. The observed decrease in upward rotation during active shoulder abduction is likely the result of inhibition of the dynamic scapular rotators. The serratus anterior and lower trapezius are especially sensitive to shoulder kinematic perturbations and may be prone to inhibition.[131] Burkhart et al.[126] believe inhibition of the serratus anterior and lower trapezius is chiefly the result of an increased amount of GIRD. In time, the static and dynamic restraints of the scapula may be affected with a loss of scapular control. One manifestation for the loss of scapular control is decreased upward rotation.

Specific to swimming, alterations in scapular kinematics are seen in individuals with stiff latissimus dorsi,[132] training sessions with individuals with impingement,[118] and across training seasons.[133] In asymptomatic swimmers, latissimus dorsi stiffness was correlated with increased scapular upward rotation and posterior tilt.[132] The authors hypothesized that increased stiffness in the latissimus dorsi causes scapular dyskinesia due to changes in the pull of the latissimus dorsi on the inferior border of the scapula.[132] These alterations in scapular kinematics may increase the risk of shoulder injury, as well as decreased performance due to limited internal rotation scapula of the scapula during the swimming stroke.[134-136] Su et al[118] compared scapular kinematics pre and post practice in a group of swimmers with impingement and in an injury-free group. Scapular kinematics remained unchanged in the injury-free group following a training session; however, swimmers with impingement reported with significantly decreased scapular upward rotation, particularly at 45°, 90°, and 135° of humeral elevation. These findings indicate the individuals who continue to practice with impingement may be further contributing to their pain due to altered scapular kinematics. In addition to alterations in one training session, research has identified changes in scapular kinematics that occur over the course of the 6-week training season.[133] Interestingly, this study found that swimmers' scapulae became more internally rotated, protracted and elevated at the post-intervention screening compared to pre-intervention regardless of group assignment. The changes in scapular kinematics may be attributed to increased tightness of the posterior shoulder and pectoralis major and minor muscles that developed in response to increasing training intensity. Individuals with posterior shoulder tightness and/or tight pectoralis muscles have been found to have increased anterior tilt, internal rotation, and downward rotation.[130] Therefore, muscle imbalances and tightness that develop due to the increased swim training may be responsible for the increased protraction and internal rotation at the post-testing.

Altered Range of Motion (ROM)

Glenohumeral rotational range of motion is often measured clinically to evaluate adaptations in internal and/or external rotation range of motion. In unilateral overhead athletes, particularly baseball, range of motion characteristics are compared side-to-side to evaluate adaptations that occur on the throwing limb. Due to the demands of the overhead throwing motion, a typical baseball player presents with greater humeral external rotation (external rotation gain) and less internal rotation on the dominant limb (glenohumeral internal rotation deficit (GIRD)).[48,137-141] compared to their non-dominant limb. A typical adult-age baseball player presents with 10-17° of GIRD on the dominant limb.[137,141-143] Loss of humeral internal rotation ROM beyond this range has previously been identified as a risk factor for shoulder and elbow injury, such as internal impingement,[23] superior labral lesions,[144] and ulnar collateral ligament injury.[145]

While these side-to-side rotational range of motion variables are easily identified in baseball athletes, who are single-arm dominant, these anatomic adaptations are more difficult to identify in swimmers, who use both arms.[146] Although the sport of swimming is bilateral, handedness and additional sports participation cause differences in bone and muscular development, leading to dominant side development that is evidenced in the pool during the catch and pull phases of the freestyle stroke.[147] Despite having a dominant and nondominant side, adaptations due to the sport are expected to develop on both sides, making side-to-side comparisons in range of motion challenging. Although significant differences may not exist between dominant and non-dominant limbs in competitive swimmers, it is known that compared to controls, swimmers have decreased internal rotation range of motion compared to controls.[8,148] In addition, it has previously been shown that youth and high school swimmers have significantly greater internal rotation range of motion than college/masters swimmers, highlighting adaptations that may be occurring due to swim training throughout the life span.[149] In baseball, deficits in range of motion and the development of GIRD have previously been attributed to subtle microtrauma to the static and dynamic restraints of the glenohumeral joint from the repetitive throwing, contracture of the posteroinferior joint capsule, and osseous adaptation of the humerus.[137,141,142,150-152] Because the stresses placed on the shoulder during swimming are similar to the overhand throwing motion, deficits in internal rotation range of motion compared to controls may develop because of the physical adaptations that occur. Hypertrophic changes from the high distraction forces placed on the shoulder during swimming may be the cause of thickening of the posterior glenohumeral capsule, which has been correlated with lesser humeral rotation ROM.[142]

Stiffness of the posterior shoulder musculature may also play a significant role in restricting internal rotation ROM. Hung et al[152] demonstrated that stiffness of the teres minor, infraspinatus, and posterior deltoid correlated with a loss of internal rotation in patients diagnosed with stiff shoulder. Literature evaluating the effects of stretching in overhead athletes suggests that muscle stiffness contributes to humeral rotation ROM. Both Laudner et al[153] and Oyama et al[154] demonstrated that internal rotation can be increased immediately after posterior shoulder stretching, suggesting a muscular contribution to humeral rotation ROM. Similar to the posterior glenohumeral capsule, the hypothesis is that stiffness develops in the posterior shoulder musculature in order to counteract the distraction forces that occur during the swimming motion.

In addition to the soft tissue contributors discussed above, the amount of humeral rotation ROM is also a function of the amount of humeral retrotorsion present in the upper extremity.[137,141,150,151,155] Humeral retrotorsion represents the amount that the distal humerus is twisted relative to the proximal humerus. The contribution of humeral retrotorsion to humeral rotation ROM may be especially large in overhead athletes, given the torsional moments that are placed on the humerus during the act of throwing.[156] The dominant limbs of throwing athletes repeatedly show more humeral retrotorsion, shifting the glenohumeral rotation arc toward the external rotation direction, thus decreasing internal rotation range of motion.[137,141,150,157,158] This decreased internal rotation results in the deceiving appearance of having posterior shoulder hypomobility, prompting clinicians to prescribe a stretching program, when in fact the soft tissue tightness may not be the only factor causing decreased internal rotation range of motion. Humeral retrotorsion in swimmers has not been shown to develop to the same extent that is commonly seen in baseball;[159] however, because swimmers place a similar stress on the shoulder to the overhead throwing motion, theoretically, swimmers may be prone to the development of humeral retrotorsion.[160]

Swimmers may also present with adaptations in external rotation range of motion. Previous research has identified alterations in external range of motion as one of the primary risk factors for the development of interfering shoulder pain and serious shoulder injury in competitive swimmers.[46] Swimmers in the high external rotation range of motion group (greater than 100°) were 8.1 times more likely to develop interfering shoulder pain and 35.4 times more likely to sustain a serious shoulder injury than those in the reference group (93-99° external rotation range of motion). The excessive external rotation range of motion can lead to gradual stretching of the capsular collagen over time which leads to increased anterior capsular laxity.[123] It has been demonstrated in cadavers that excessive external rotation results in elongation of the anterior band of the inferior glenohumeral ligament complex, resulting in a significant increase in anterior and inferior capsular translation.[124] This indicates that swimmers may develop laxity from repetitive external rotation that may manifest as anterior instability or microinstability, allowing the humeral head to translate anteriorly during the recovery phase and causing the posterior rotator cuff musculature to be impinged on the posterosuperior glenoid rim.

In addition to excessive external rotation range of motion, swimmers with limited external rotation range of motion are also at an increased risk of injury.[46,161] Previous research found that competitive swimmers in the low external rotation range of motion group (below 93°) were at 12.5 times greater risk of developing interfering shoulder pain and a 32.5 times greater risk of developing a serious shoulder injury than those in the reference group (93-99°).[46] External rotation range of motion is important as the swimmer completes the recovery phase of the freestyle stroke. If a swimmer is limited in external rotation range of motion, they may be prone to the development of impingement, as limited external rotation range of motion has been shown in cadavers to increase contact of the superior glenoid and humeral head, thus promoting internal impingement.[161] In addition, previous research has linked limited external rotation range of motion with the development of subacromial impingement.[58]

Subacromial Space Distance

A decrease in the subacromial space distance increases the mechanical compression on the contents of the subacromial space and is an intrinsic risk factor for the development of impingement. With added mechanical compression on the contents of the subacromial space (supraspinatus tendon, long head of the biceps tendon and subacromial bursa), the risk for the development of impingement is increased. Use of diagnostic ultrasound for the measurement of subacromial space distance has previously been shown to be a reliable tool between radiologists[34,36] and non-radiologist clinicians.[36] In addition, ultrasonographic assessment of subacromial space distance has been found to be a valid assessment when compared with the traditional radiographic measure [35] and has been suggested to be an acceptable replacement for X-rays in clinics. A decrease in subacromial space, identified using diagnostic ultrasound, has been found on the affected shoulder of individuals with impingement syndrome when compared to healthy controls.[38] One explanation of the decrease in subacromial space in individuals with impingement syndrome is a loss of scapular control manifesting as altered scapular kinematic patterns. This theory is supported by a study that found that tennis players with scapular dyskinesia have been found to have significantly smaller subacromial space distance than individuals who do not have scapular dyskinesia.[37] This study indicates that individuals with a decreased subacromial space distance may benefit from an intervention program aimed at improving scapular stabilizers in order to better control the scapula and optimize the subacromial space distance. Furthermore, previous literature has found a strong, direct correlation between increases in the subacromial space distance and functional outcomes as measured by the Western Ontario Rotator Cuff Index in impingement patients, indicating that improvements to this characteristic both decrease the chance of injury, but also the functioning of the athlete.[34]

Posture

Anecdotally, swimmers are notorious for having poor posture.[6,10] Swimmers are characterized as having forward head, rounded shoulders and increased thoracic kyphosis, which can affect scapular kinematics, muscle strength and range of motion.[31-33,162] The most common cause of postural deviations is due to altered muscle lengths that develop due to the demands of training. Forward head posture generally means that the suboccipital muscles and the upper trapeziums' are overly tight coupled with weak deep neck flexors.[163] Forward shoulder posture along with an increase in thoracic kyphosis indicates tight pectoral muscles coupled with weak middle and lower trapezius.[163] Muscle length changes that occur in swimming are due to the repetitive nature of the sport and the fact that the majority of training is performed using the freestyle stroke where the swimmer is prone in the water using the anterior musculature, including the pectoral muscles, the serratus anterior and the upper trapezius to generate power in the water.[164] The constant use of this anterior musculature causes the muscles to become over-developed, tight and short and pulls the shoulder girdle forward in relation to a plumb line or an imaginary plumb line.[164] The anterior pull on the shoulder girdle by the anterior musculature puts the posterior muscles, involved in pulling the scapulae back towards the spine, on a constant stretch that eventually causes them to lengthen and weaken which contributes to forward shoulder posture.[164]

Because of the soft tissue contribution to forward shoulder posture, stretching and strengthening intervention programs have been studied to evaluate their effectiveness in improving postural abnormalities.[32,162] In a study by Kluemper et al[162] a 6-week stretching and strengthening program was implemented on competitive swimmers for correction of forward shoulder posture. The treatment group performed scapular retraction, shoulder external rotation, and shoulder flexion using resistive tubing, as well as stretching the pectoralis minor while laying over a foam roller and the pectoralis major with the individuals hand linked behind their head with the a partner applying overpressure. After the 6 weeks, a significant improvement in posture was found in the treatment group, with these individuals having decreased forward shoulder posture. The positive results from this study show that compliance with a stretching and strengthening program can improve posture. A study by Wang et al[32] implemented a strengthening and stretching program on asymptomatic participants with forward shoulder posture and evaluated its effect on three-dimensional scapular kinematics and strength. Participants performed scapular retraction, shoulder shrugging, shoulder abduction, shoulder external rotation and corner stretching using resistive tubing three times per week. After the intervention, a significant increase in isometric strength for external rotation, internal rotation and horizontal abduction occurred. However, no significant difference was found in three-dimensional scapular position at rest after the 6 weeks, although change in scapulohumeral rhythm was found, when the arm was actively elevated to 90°. The scapula was found to be less upwardly rotated, superiorly translated and more internally rotated, indicating the increased contribution from the glenohumeral joint to the elevation movement. After the exercise program, the scapular stabilizing muscles were better able to stabilize the scapula on the thorax and help to prevent impingement.

Faulty postural alignment and poor posture over time can lead to abnormal stress on tissues that may contribute to shoulder pain.[163] Poor posture may be implicated in shoulder pain indirectly through muscle imbalances. These muscle imbalances may alter biomechanics, contribute to secondary impingement, contribute to joint instability and contribute to fatigue. In a study by Kebaetse et al[31] individuals in a slouched posture had significantly less upward rotation and posterior tipping, as well as increased internal rotation of the scapula between 90° and maximum shoulder abduction occurred when compared to an upright posture. This study also found a 16.2% decrease in the glenohumeral muscle strength and ability to generate muscle force in the slouched posture.[31] The alterations in scapular kinematics and decreased muscle strength associated with a slouched, forward shoulder posture have been theorized to decrease the subacromial space distance, thus increasing the risk of impingement.[13,37,165,166] Forward shoulder posture may decrease the width of the subacromial space in some increasing mechanical compression on the rotator cuff, long head of the biceps, and subacromial bursa.[167,168] Although many studies have indicated poor posture as a cause of injury, neither symptomatic nor asymptomatic subjects with impingement syndrome had set postural deviations.[169] Unique alterations were present in each of the individuals.

The authors of this study suggest that postural deviations might be from stresses placed on the shoulder during development or osseous asymmetries, instead of postural deviations. The research on the role of posture in “swimmer’s shoulder” has been inconclusive and further research needs to be conducted to better understand this factor.[32,33,162,169,170]

Supraspinatus Tendon Thickness

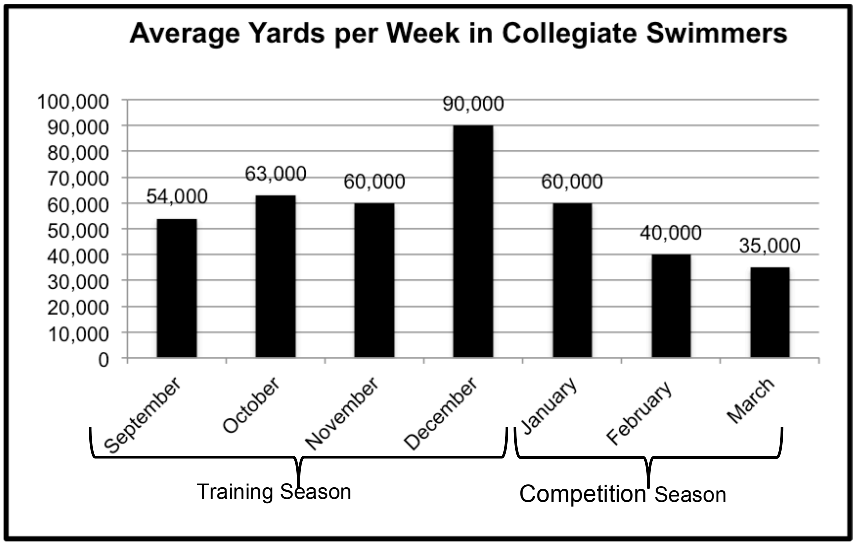
A recent study by Sein et al[8] has suggested swim-volume-induced supraspinatus tendinopathy with associated supraspinatus tendon thickening to be an intrinsic risk factor for the development of swimmer’s shoulder. This study found that all individuals with supraspinatus tendinopathy also had significantly greater supraspinatus tendon thickness values that were associated with the number of hours swam and amount of yardage completed per week, indicating that the volume of training is a significant contributor to the changes within the supraspinatus tendon and potentially the development of shoulder pain. A thickened supraspinatus tendon would in effect narrow the subacromial space and may promote impingement. Supraspinatus tendon thickening has been found in elite injured and uninjured collegiate baseball players when compared to healthy controls.[39] This retrospective study design did not find significant differences between injured and uninjured baseball players, but a prospective study design is needed to determine if the amount of change is related to injury. Tendon thickening has prospectively been found to occur in animal models evaluating the effect of overuse protocols.[77,79,171,172] In the supraspinatus tendon of rats exposed to an overuse running protocol, there was an increased cross sectional area of the supraspinatus tendon with a decreased tendon composition quality after just 4-weeks of training.[79] This finding indicates that the supraspinatus tendon thickening in rats, and potentially in swimmers, occurs as a result of the repetitive microtrauma that occurs due to overuse.

Extrinsic Risk Factors

Training Volume

The swimming season is broken into a cardiovascular/endurance phase that occurs in the training season and a taper period that occurs in the competition season. During the training season, competitive swimmers perform a large volume of yardage with high intensity practices in order to gain strength and power.[26] As the competition season approaches, swimmers begin to taper, which allows for muscle recovery and rest, ultimately optimizing physiological and psychological components to maximize performance in competitions.[27,28] Pilot data collected by members of the research team during the 2011-2012 competitive collegiate season demonstrate the described training periods and approximate training during the collegiate season **(Figure 3).**[173] Volume of swim training has been proposed as a risk factor for the development of swimmer’s shoulder, as it leads to fatigue in scapular stabilizing musculature, development of muscle imbalance, and adaptations of the modifiable intrinsic physical characteristics that increase the risk of injury in competitive swimmers.

Figure 3: Average Yards Per Week in Collegiate Swimmers



Stroke Biomechanics

Because of the large volume of yardage that is completed during the endurance/cardiovascular phases of training, up to 80% of all practice time is spent performing freestyle, regardless of stroke specialty.[11] While there are four strokes in the sport of swimming (butterfly, backstroke, breast stroke, and freestyle), freestyle is performed most often by competitive swimmers during training, so abnormal mechanics during this stroke would theoretically have the greatest impact on injury/pain development.[8,11] Further, previous research has observed that there is not a correlation between stroke specialty and rate of shoulder pain in collegiate swimmers.[174]

The traditional freestyle stroke is broken into 3 distinct phases: hand entry, pull through, and recovery.[7,122] The hand entry phase occurs as the swimmer places his/her in the water to prepare for the major power phase- pull-through. During pull through, the arm position creates a large moment arm and the hydrodynamic force causes the shoulder to elevate beyond the maximum active angle.[122] This forced elevation causes compression in the subacromial space and creates shoulder impingement for approximately 10% of the stroke time.[97] The arm should move in a straight back motion pushing against the water to propel the body forward. During the entire pull phase, the elbow should always be kept high, by flexing the arm, slightly abducting and internally rotating the shoulder.[122] The high elbow position places the muscles of the shoulder at mechanical advantage, allowing for the maximal force production.[175]. Although this advantage is helpful in swimmers, it narrows the subacromial space leading to an impinged position throughout the pull phase.[122] Following the propulsion phase is the recovery phase, which is the time from hand exit to the reentry of the hand into the water. While the elbow is held high in the air with abduction and external rotation of the shoulder, the arm should be relaxed to allow the musculature recovery time. This phase is the most common phase for impingement to occur, affecting those who complete the recovery phase with a large internal rotation angle the most.[97]

The development of swimming mechanics has concentrated on performance improvements with little focus on biomechanical advancements to contend with the vigorous demands placed on swimmers' shoulders. Swimming with improper freestyle mechanics has been suggested as a dominant risk factor for shoulder pathology and pain.[4,12,51,59,97,176,177] A biomechanics study focusing on shoulder impingement during freestyle has shown male collegiate swimmers are in an impinged position, where there is contact between the greater tuberosity of the humerus and the acromial arch as well as stress on the structures in this space, for about 25% of their freestyle stroke time.[97] This illustrates that even swimmers employing an unflawed freestyle stroke will experience a moderate amount of shoulder impingement. However, swimming with a freestyle stroke that includes biomechanical errors is thought to increase the time spent in the impingement position and leads to undesirable shoulder problems. Theoretical stroke biomechanical errors that may be related to shoulder pain have been identified. These errors include improper hand entry angle, hand entry position, pull-through pattern, elbow position during pull-through, elbow position during recovery, body roll angle, and head carrying angle.[4,40,51,97,135,178-180] The correct and incorrect biomechanics, as well as the relationship of the incorrect biomechanics to injury is presented in **Table 1.**[173] A stroke biomechanics assessment is important for all competitive swimmers to help identify contributors to existing and potential pain. While swimming with improper stroke mechanics has been established as a theoretical risk factor for shoulder pain and injury, a clear correlation between faulty freestyle stroke technique and shoulder pain has yet to be identified through biomechanical research.

Table 1: Summary of Stroke Errors

Stroke Phase	Correct Freestyle Biomechanics	Incorrect Freestyle Biomechanics	Relevance of Incorrect Biomechanics to Shoulder Pain
Hand Entry	Hand enters water forward and lateral to the head, medial to the shoulder.[135]	Hand enters further away from or crosses the midline of the long axis of the body.[4,51,181]	Increases impingement to the anterior shoulder.[4] Mimics Neer impingement testing position[181]
	Little finger or fingers first hand entry.[4]	Thumb first hand entry.[4]	Stresses the biceps attachment to the anterior labrum.[4]
Pull-Through	Elbow kept higher than hand and points laterally throughout pull.[180]	Dropped elbow during pull-through.[97]	Increases external rotation, placing muscles of propulsion at mechanical disadvantage.[40]
	Swimmer should use a straight back pull-through.[180]	S-shaped pull through or excessive horizontal adduction past body midline during pulling.[4]	Increases time spent in the impingement position.[4] Mimics Hawkins Kennedy impingement testing position of horizontal adduction, flexion, and internal rotation.
Recovery	Elbow kept higher than the wrist throughout the recovery phase[4,97]	Dropped elbow during recovery phase[181]	Leads to an improper entry position with the elbow entering the water before the hand. The water will cause an upward force on the dropped humerus, leading to its superior translation and subacromial impingement.[181]
	Body roll of ~45° along the longitudinal axis of the body[4,180]	Body roll that is greater or less than 45° [4]	Excessive roll can lead to crossover entry position, during the pull phase, or during both phases. A lack of roll during recovery can increase mechanical stress on the shoulder and lead to improper hand entry position.[4]
All Phases	Head in neutral position. Imagine line through center of head and extending through spine.[4]	Head carriage is in eyes forward position.[4]	Eyes forward head position increase impingement by impending normal scapulothoracic motion.[4]

Equipment Use

During training, hand paddles are often utilized as an adjunct to traditional training, in order to increase propulsive efficiency. Hand paddles are rectangular pieces of plastic that are attached to the hands by rubber tubing and are used to improve the catch of the water and the power of the pull through stroke. While many coaches believe these are beneficial adjuncts to practice, many studies have identified hand paddle use to be linked to the development of shoulder pain.[40,182] Hand paddles that are larger than the size of the hand normally or do not have holes to allow for drainage of water may increase the stress on the shoulder as it places a greater strain on the musculature during the pull through phase. In addition, kickboards are often used as recovery or to focus on lower extremity power, however, holding the kickboard overhead places the shoulder in an impingement position, and may increase the stress on shoulder musculature. Kickboard usage has also been linked to shoulder pain.[182] While some of the evidence on the use of equipment in training is inconclusive, it is important to understand the theoretical risk that exists with the use of training equipment.

Rest and Recovery

Due to the current popular theory of swim training, swimmers train at high volumes with a large number of yards being performed per practice with many practices a week.[183] This training load does not allow competitive swimmers adequate time to rest and recover between practices. This repetition can cause muscular fatigue, which may result in alterations in physical characteristics, including altered scapular kinematics that may increase the risk of injury.[118] Previous studies have identified adaptations in scapular kinematics that may promote injury or alter muscle functioning following a fatigue protocol, including increased scapular upward rotation and external rotation, as well as clavicular retraction.[184] Associated with these changes in scapular kinematics, were decreases in EMG activity in the upper trapezius, serratus anterior, anterior and posterior deltoids, and infraspinatus following fatigue, with the greatest decreases in the infraspinatus and deltoids.[184] With fatigue, there is an alteration in scapular kinematics and muscle activation that may increase the risk of shoulder pain. Swimmers need to be given time to recover, as rest allows muscles to return to a state of readiness after the onset of fatigue by replenishing proper chemical levels for muscle contraction, such as calcium ions and energy stores, and for minor injuries to heal.[185] Unlike baseball pitching, there are no participation guidelines or indicators of rest following these extreme loads of training.

On a more global scale, increased training load in males has been shown to results in decreases in total testosterone and free testosterone, as well as increased circulating creatine kinase.[186] These hormonal changes were also linked to a decrease in performance and mood, thus the authors suggested these hormonal alterations as markers that could be used to evaluate for overtraining syndrome. Overtraining syndrome is a neuroendocrine disorder that occurs with high volume training with inadequate periods of recovery that presents with decreases in performance, training quality, training load, fatigue, frequent illnesses, and altered mood.[187,188]

Summary

Interfering shoulder pain is reported in 45-87% of swimmers at some time during their careers.[10-12,105,189,190] One of the primary causes of this shoulder pain is hypothesized to be overuse of the shoulder during training, as competitive swimmers train 11,000-15,000 yards per day, 6-7 times per week.[8,12,162] Due to these high levels of training, swimmers develop altered physical characteristics that predispose them to “swimmer’s shoulder,” which is the general term for overuse injury in swimming athletes.[6,7] Clinically, athletic trainers see a high percentage of athletes reporting for treatment of shoulder pain during the training season, which is a period at the beginning of the season where swimmers perform large yardage volume and high intensity practices in order to gain strength and power.[26] Due to this training load, it is hypothesized that physical characteristics of swimmers change due to participation factors and predispose the athlete to shoulder injury. Research is needed to determine the effect of swim training on these physical characteristics that may be causative of impingement and the development of swimmer’s shoulder. Moreover, focusing on a youth swimming population will help to identify the effects of participation and alterations in physical characteristics that occur early in an athlete’s career and potentially prevent shoulder pain from affecting the entire career of the athlete.

CHAPTER III

METHODS

3.1 Overview

Our *overall research objective* is to establish a screening tool that can be used to identify shoulder injury risk factors and provide information regarding development of intervention programs and practice guidelines in competitive swimmers. The *objective of this project* was to determine the effect of swim training on shoulder physical characteristic and pain and to evaluate the relationship between changes in these variables and participation factors. In order to meet our aims, a cohort repeated measures design was used to evaluate changes in physical characteristics over the course of the training season in competitive swimmers. Forty-five male and female swimmers from local North Carolina club swimming teams aged 13-18 and 31 non-overhead athletes controls were recruited for participation. All individuals participated in a pre-season testing session in which demographics were collected and physical characteristics were measured. These testing procedures were repeated at the middle and end of the training season, approximately 6 and 12 weeks following the preseason assessment. In addition, club team coaches provided swimming participation information over the training season in order to evaluate relationships between changes in physical characteristics and participation factors. *In order to accomplish our aims and test our research hypotheses, the following detailed experimental methods were employed.*

3.2 Population and Recruitment

Swimming Group

Participants were recruited for both a swimming group and a control group. Participants were recruited from local club swimming teams from the state of North Carolina that the research team has previously used as participants in research studies. Participants were both males and females between the ages of 13 and 18 years old. Participants were included in the research study if they meet all of the following criteria:

- Member of a senior (top training level) team on their club team
- Regularly train at least 4 times per week, 1-2 hours each practice session
- Not currently experiencing back, neck or shoulder pain that limits their ability to participate.

Participants were excluded from the research study if they meet the following criteria:

- Have less than 2 years of competitive swimming experience
- Have limitations in practice or are unable to complete practices fully due to pain, injury, or illness for more than 2 weeks during the training season.
- Currently using any type of external, correctional posture device
- Have a history of shoulder surgery.[113]

Control Group

Control Participants were included to account for changes in physical characteristics that occur due to maturation. Control group Participants were recruited from local soccer and track and cross country leagues. Control group Participants were non-overhead athletes between the ages of 13 and 18 years old, matched to the swimming participants on age and gender. Control Participants were included in this research study if:

- Have not participated on an organized team of an overhead dominant sport for more than 1 year (ex. Baseball, softball, tennis, volleyball, swimming)
- Were not experiencing back, neck, or shoulder pain that limited participation during the course of the study

Control Participants were excluded from this research study if:

- Have a history of shoulder surgery.[113]
- Currently experiencing any shoulder pain
- Currently using any type of external, correctional posture device
- Performing rehabilitation (strengthening and stretching) that targets upper extremity physical characteristics
- Development of back, neck or shoulder pain the limits their ability to participate in activity for more than 2 weeks.

3.3 Research Design

A prospective cohort repeated measures research design was utilized in the current study. All participants in this study partook in three data collections: pre training season, mid-training season (approximately 6 weeks) and post-training season (approximately 12 weeks). Data collection occurred prior to the start of a team practice and participants filled out demographic information and physical characteristics were measured. In addition, coaches of the club teams tracked athlete participation throughout the team's training season, as well as any injuries that occur.

3.4 Procedures

When the participant reported for the initial screening, he/she was introduced to the research study and then read and signed a consent form approved by the University of North Carolina at Chapel Hill Institutional Review Board. The participant then completed a survey to evaluate demographics and participative measures of shoulder pain and function. The participant then underwent the pre-season testing, which included assessments of shoulder range of motion, posture, pectoralis minor length, and subacromial space distance. The demographics and pain/function questionnaires and the physical characteristics assessment were repeated at 2 time intervals during the training season, 6-weeks and 12-weeks. Details of each procedure are discussed below.

Demographics

Each participant completed a demographics questionnaire with the help of a parent/guardian **(Appendix 1)**. The questionnaire included questions about years of experience, event specialization, practice requirements, pain medication use, experience of shoulder pain, previous injury history, and height/weight.

In addition, at the initial time of screening, information was provided in order for the research team to estimate skeletal maturity **(Appendix 2)**. This information included each participant's age, birth date, height and weight were obtained. Parents reported their heights. Using this information, the Khamis et al[191] protocol was used to predict mature height. Current height of the participant was expressed as a percentage of his predicted mature height to provide an estimate of biological maturity status. Physical maturity using this method calculated for individuals who did not know the height of the both of their parents- either because of divorce or adoption. This estimation of skeletal maturity has been validated using radiographic measures of skeletal maturity.[192] In addition to traditional demographic information, this measure provides additional details about the physical maturity of the individual, which may be a mediating factor for changes that are seen in the participants.

Participants also completed the pubertal development scale **(Appendix 2)**. The Pubertal Development Scale is a self-report measure of pubertal development that asks individuals to answer questions about their development and assesses multiple dimensions of maturation.[193] Individuals answer questions regarding growth spurt, changes in body hair, and skin changes. Male subjects report on facial hair growth and voice changes, while females reports breast development and age at menarche.[193] The Pubertal Development Scale has been found to be a reliable and valid method of assessing physical maturation, as it correlates with Tanner Stages, physician rankings, and basal measures of pubertal development.[193-195]

Subjective Measures of Pain and Functioning

Several measures of subjective shoulder pain and functioning were used in order to evaluate baseline measures of shoulder pain and dysfunction and track how these change over the course of the training season. Four shoulder scales were used for evaluation of shoulder pain and functioning. Participants filled out the surveys for both their right and left shoulders. These scales include: Modified Oxford Shoulder Scale, Shoulder Pain and Disability Index, Penn Shoulder Scale, and the Functional Arm Scale for Swimmers. Each of these shoulder scales is discussed in greater detail below.

The Oxford Shoulder Scale is a 12-item patient report scale of pain and limitations during activities of daily living.[196] The survey asks participants to recall pain and limitations over the past 4 weeks **(Appendix 3)**. The questions on the Oxford Shoulder Scale are split into 2 groups: 4 questions related to pain and 8 questions related to activities of daily living, where participants report pain or limitation on a scale of 0-4. Total scores range between 0-48, with greater OSS scores indicating greater dysfunction. The original OSS scale asks participants to recall their shoulder pain and limitations over a 4-week period. Participants completed the shoulder scale for both their right and left arms. The Oxford Shoulder Scale has been shown to be a reliable measure with high test-retest reliability and correlated well with the Shoulder Pain and Disability Index and the pain and physical domain of the Western Ontario Rotator Cuff Index.[197] Due to the agreement, reliability, and construct validity of the Oxford Shoulder Score with other previously validated assessments, it is an acceptable instrument to use for outcomes measures of shoulder pain and functioning.[197]

The Shoulder Pain and Disability index (SPADI) is 13-question self-report measure that evaluates the participant's pain and functioning at a specific time (data collection days) (**Appendix 4**).[198] Participants answered 5 questions related to the pain dimension and 8 questions related to the functioning dimension. A total SPADI score was calculated on a scale of 0-100 with a greater SPADI score indicating greater pain or impairment. The SPADI has been shown to be a reliable and valid measure[199,200] and is an effective tool for evaluating patients with improving or deteriorating conditions.[200]

The Penn Shoulder Score was used to calculate pain scores for each participant's left and right shoulders (**Appendix 5**). The Penn shoulder score is a composite score calculated from 24 questions that evaluate shoulder pain, satisfaction, and function.[201] The Penn Shoulder Score has been demonstrated to be a valid and reliable measure for reporting shoulder pain in patients with various shoulder disorders.[201]

Functional Arm Scale for Swimmers (FASS) is a modification of the Functional Arm Scale for Throwers, which was previously developed as a region-specific self-report measure for throwing athletes to use to assess pain and limitations specific to the demands of the sport.[202] The FAST was designed to assess pain, limitations, and symptoms of the shoulder in throwing athletes, by specifically asking about limitation within their sport, as well as how the injury/pain has affected their life. The FAST has been found to be positively correlated with self-reported pain and injury history in adolescent baseball players.[203] Although the FAST did not correlate well with the Disabilities of Arm, Shoulder, and Hand (DASH), the DASH also did not correlate with self-reported pain and injury history in the sample used, indicating that the FAST may be a better representation of impairments in an active, youth population.[203] The FAST was modified by making it applicable to a swimming population for the development of the Functional Arm Scale for Swimmers (FASS) **(Appendix 6)**.

Range of Motion

Range of motion testing of glenohumeral internal/external rotation and horizontal adduction range of motion was performed using methods described by Norkin and White[204] and Myers et al.[205] Range of motion was assessed using a digital inclinometer (The Saunders Group, Inc. Chaska, MN). Detailed methods for each motion are listed below.

Internal and external rotation range of motion were assessed with the participant lying supine on a portable treatment table with 90º of both shoulder abduction and elbow flexion. Scapular stabilization was provided by the investigator through a posteriorly directed force at the acromion to isolate motion at the glenohumeral joint. The investigator rotated the limb to end range in internal rotation and external rotation while a second investigator aligns the digital inclinometer with the forearm and records the humeral rotation angles **(Figure 4).** The dependent variables assessed were dominant and non-dominant passive humeral internal rotation, external rotation and total of arc of humeral motion (deg). Reliability and precision of the measurements obtained previously by members of the research team are included in **Table 2**.

Horizontal adduction range of motion was measured to assess posterior shoulder tightness. The participant was lying supine on a portable treatment table (**Figure 4)**. The participant's scapula was passively stabilized in full retraction.[205]

The humerus was elevated to 90º abduction and neutral rotation. The humerus was then passively horizontally adducted while the scapula remains fully retracted. At the end range of motion, a second investigator measured the humeral horizontal adduction angle with a digital inclinometer. This value was recorded as the amount of posterior shoulder tightness for that participant. The dependent variable was posterior shoulder tightness. Reliability and precision of the measurement obtained previously by members of the research team is included in **Table 2.**

Figure 4: Range of Motion Assessment- (A) Internal Rotation Range of Motion Measurement (B) External Rotation Range of Motion Measurement (C) Posterior Shoulder Tightness Measurement

Table 2: Range of Motion reliability, precision, and minimum detectable difference

	ICC	*SEM*	*MDD*
Internal Rotation	0.98	1.4°	3.8°
External Rotation	0.99	1.2°	3.3°
Horizontal Adduction	0.93	1.8°	4.9°

Forward Head and Shoulder Posture

Reflective markers were placed on the dominant side of each participant on the following anatomical landmarks: tragus, C7, and anterior tip of the acromion.[206] While standing in front of a horizontal reference line, participants performed 3 overhead squats and then be instructed to stand in “a relaxed position” while a picture is taken in the sagittal plane. Following the initial photograph, participants was then instructed to complete three additional overhead squats. Following the series of three squats, the Participants were instructed to “relax” and “stand in normal position” while photographs are repeated in the sagittal plane. Participants performed one additional set of three squats, “relaxing” and “standing in normal posture” for subsequent photographs to be taken. Reliability, precision, and minimum detectable difference of the measurement obtained during pilot testing are included in **Table 3.**

Table 3: Posture reliability, precision, and minimum detectable difference

	ICC	***SEM***	***MDD***
Forward Head	0.98	0.7°	2.0°
Forward Shoulder	0.99	0.9°	2.5°

Pectoralis Minor Length

Pectoralis minor length was measured with the participant lying supine on the table. Pectoralis minor muscle length was measured using vernier calipers (Westward Tools, Edmonton, AB, Canada). The pectoralis minor length was defined as the distance between the medial-inferior aspect of the coracoid process to the anterior-inferior edge of the 4th rib just lateral to sternocostal junction **(Figure 5).** [207] This method of measurement of the pectoralis minor muscle length has been validated using cadavers.[207] Based on a high intraclass correlation coefficient and a small root mean square error between the pectoralis minor length measured from cadaver dissection and using palpable landmarks, the authors concluded that this is a valid method for determining pectoralis minor length in vivo. Reliability, precision, and minimum detectable difference of the measurement obtained during pilot testing are included in **Table 4.**

Figure 5: Pectoralis Minor Length

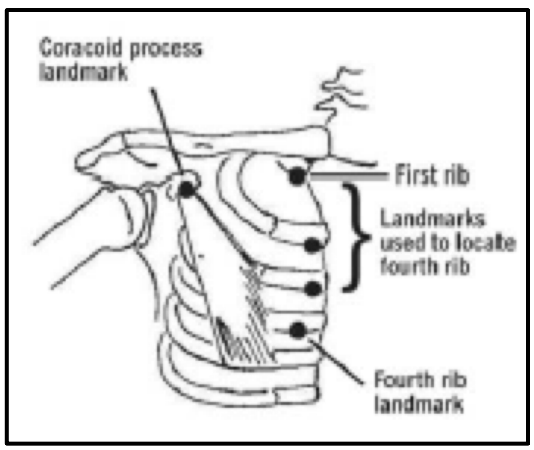


Table 4: Pectoralis Minor Length reliability, precision, and minimum detectable difference

	ICC	***SEM***	***MDD***
Pec Minor Length	0.92	0.4cm	1.2cm

Measurement of Subacromial Space Distance

Subacromial space distance was measured using a portable diagnostic ultrasound machine (LOGIQe, General Electric, Milwaukee, Wisconsin, USA) using procedures previously defined by Wang et al.[39] The subacromial space was defined as the distance between the inferior tip of the acromion to the humeral head. The participant was assessed seated in a chair with their forearm resting on his/her thigh in pronation **(Figure 6).** Sound coupling gel was applied to the ultrasound transducer, which was then placed in the coronal plane of the shoulder. When the lateral acromion and humeral head can clearly be visualized, the image was saved for later analysis. Three trials were performed bilaterally. After measurements have been taken at all of the 3 time points, a research assistant re-labeled the stored images, so that the primary investigator who was evaluating the subacromial space distance was blinded to testing session to prevent any bias from entering the assessment. Reliability, precision, and minimum detectable difference of the measurement obtained during pilot testing are included in **Table 5.**

Figure 6: Subacromial Space Distance Measurement

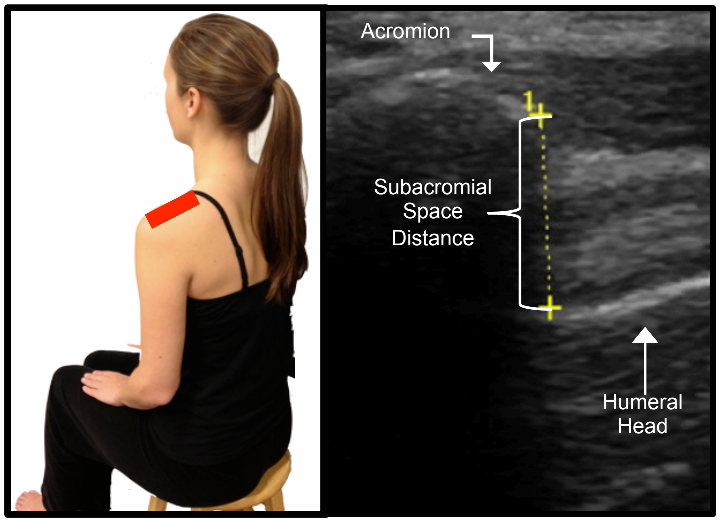


Table 5: Subacromial Space Distance reliability, precision, and minimum detectable difference

	ICC	*SEM*	*MDD*
Subacromial Space Distance	0.87	0.05cm	0.1cm

Participation Tracking

At the 6-week and 12-week follow up sessions, participants completed demographics forms to report information regarding practices, injuries, and pain over the past 6-weeks only. Participants were able to determine number of practices per week and yardage per week by referencing swimming notebooks that each participant kept for their coaches. Reported participation numbers were verified by coaches of each of the swimming teams. From these surveys, yards per week, total yards, dry-land training were able to be calculated and presence of shoulder pain, injuries, and use of pain medication were quantified.

3.5 Data Reduction

Subjective Measures of Pain and Functioning

Total scores were calculated for each of the scales used for the subjective measures of pain and functioning. Each of the 12 questions on the Oxford Shoulder Score are answered on a Likert scale that is assigned point values, with 0 indicating no pain or limitations and 4 indicating the greatest amount of pain and limitation. Each individual question was scored and then the overall score was calculated as a sum of the response score for each of the questions, resulting in a continuous score between 0 (least severe symptoms) - 48 (most symptoms).

The participants respond to each item of the SPADI on a scale of 0-10, with 0 indicating no pain/difficulty and 10 indicating the worst pain imaginable/require help to complete task. A total score is calculated for the pain questions (questions 1-5) and the disability questions (6-13). The pain score is calculated as: $Pain\ Score\ \% = \frac{Total\ Pain\ Score}{50}\ X\ 100$ and the total disability score is calculated as: $Disability\ Score\ \% = \frac{Total\ Disability\ Score}{80}\ X\ 100$. A total SPADI score is calculated as: $Total\ SPADI\ Score\ \% = \frac{Total\ Pain\ Score + Total\ Disability\ Score}{130}\ X\ 100.$

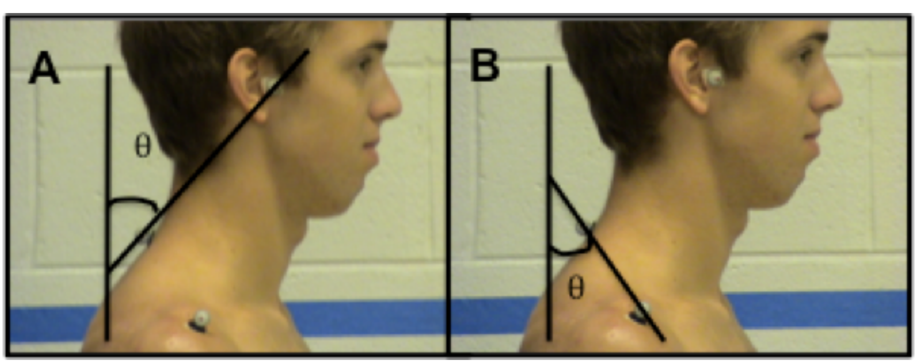
The Penn Shoulder Score questionnaire is scored out of 100 total points with 30 possible points representing the subject's pain, 10 possible points regarding shoulder satisfaction, and 60 possible points representative of their shoulder function. Based on the swimmers' responses, each of these three subscale scores were combined for a composite shoulder pain and disability score out of 100 possible points. A higher total score is indicative of greater shoulder pain and disability.

The Functional Arm Scale for Swimmers is a set of questions that are scored on a Likert scale with associated points: 1 (least pain/symptoms/limitations) – 5 (most pain/symptoms/limitations). A total score is calculated by summing the responses to each of the questions.

Physical Characteristics

Forward head and shoulder posture measures were reduced by the primary investigator using Image J software (National Institute of Health, Bethesda, MD). The landmarks that were defined by the reflective marker on each participant (tragus, C7, anterior tip of the acromion) were digitized to calculate forward head and forward shoulder angle. Forward head angle was defined as the angle of inclination of the line extending from C7 to tragus and the vertical line **(Figure 7A)**. Forward shoulder angle was defined as the angle of inclination of the line extending from C7 to the shoulder and the vertical line for each participant **(Figure 7B).**

Figure 7: Forward Head and Shoulder Angles



Pectoralis minor length will be normalized to account for differences in length due to height differences.[208] The measured length will be divided by the height (measured at the respective session) and multiplied by 100 to acquire the dependent variable of normalized pectoralis minor length.

The primary investigator measured subacromial space distance using Image J software (National Institute of Health, Bethesda, MD). Subacromial space distance was defined as the shortest distance between the anterior-inferior tip of the acromion and the humeral head **(Figure 6).** [209]

After this data reduction has occurred, three-trial means were calculated for each of the variables: range of motion (internal rotation, external rotation, horizontal adduction), posture (forward head and forward shoulder) pectoralis minor muscle length, and subacromial space distance. In addition total arc of motion was calculated as the sum of internal rotation and external rotation range of motion. Data was collected bilaterally and analysis was run separately on the dominant and nondominant arm of the athlete. Although the sport of swimming is bilateral, handedness and additional sports participation causes differences in bone and muscular development, leading to dominant side development that is evidenced in the pool during the catch and pull phases of the freestyle stroke.[147] Change scores were calculated for each variable as the difference between the measurement time (6-weeks or 12-weeks) and the baseline score.

3.6 Statistical Analysis

Descriptive statistics were calculated for demographic information, each variable, and the change score of each variable physical characteristic variable. To evaluate group differences between swimmers and non-overhead athletes at baseline for specific aim 1, independent t-tests were used to evaluate differences between forward head and forward shoulder posture in competitive swimmers and non-overhead athletes. Two-way ANOVAs (group-by-limb) were used to evaluate differences in subacromial space distance, pectoralis minor length, and ROM variables. Bonferroni post-hoc analysis were performed if significant differences were found.

To evaluate changes in physical characteristics over the course of the training season, a 2-way mixed model ANOVA (time-by-group) was used to analyze the percent change of forward head and forward posture variables. A 3-way mixed model ANOVA (limb X time-by-group) was used to analyze the percent change of subacromial space distance, pectoralis minor length, and range of motion variables. Bonferroni post-hoc analysis will be performed if significant differences are found. Pearson product-moment correlations were also to evaluate the relationship between forward shoulder posture, subacromial space distance and pectoralis minor length.

For specific aim 2, descriptive analyses were run to determine average practice demands, presence of shoulder pain, shoulder injuries, and pain scores for each of the testing periods. A 2 x 2 with-in subjects ANOVA (time-by-limb) was calculated to evaluate changes in each pain measure over the course of the training season. Bonferroni post-hoc analysis will be performed if significant differences are found. Finally, correlations were computed between the pain scores at the 6 weeks post-baseline assessment and yardage completed during this time, pain scores at the 12 weeks post-baseline assessment and total yardage completed over the training season, and percent change in physical characteristic and 6-week yardage totals and total training season yardage.

An a priori alpha level of 0.05 was set for all comparisons for statistical significance. Statistical analyses were run using SPSS version 20.0 software.

CHAPTER IV

RESULTS

4.1 Specific Aim 1

Specific Aim 1 Results

In order to address specific aim 1, we first performed a comparison of posture, subacromial space distance, pectoralis minor length, and glenohumeral range of motion (ROM) between competitive swimmers and non-overhead athletes at baseline to determine if the common profile in swimmers is due to swimming participation or if this profile may be due to factors other than swimming participation. As previously discussed, swimming is a year-round sport, so a true baseline may not be possible. For this research study, baseline was defined as the time prior to the swimming training season. While the swimmers would be swimming as part of a maintenance phase prior to this assessment, they would not be completing the high volume, intense training to build strength, power and cardiovascular endurance that is characteristic of the training season.

The study participants were 44 competitive adolescent swimmers and 31 non-overhead athletes. Complete participant demographic information is included in **Table 6.** The mean values for forward head posture and forward shoulder posture are presented in **Table 7.** Group means for dominant and non-dominant normalized pectoralis minor length, normalized subacromial space distance and glenohumeral internal rotation, external rotation, and horizontal adduction ROM are presented in **Table 8.**

Table 6: Participant Demographics

	Swimmers	Non-overhead athletes
n	44 (26F; 18M)	31 (21F; 10M)
Age (yrs)	16.5 ± 1.0	16.5 ± 1.0
Height (cm)	172.2 ± 12.9	168.8 ± 8.4
Mass (kg)	66.2 ± 10.2	57.7 ± 8.2
% Predicted Height	97.3 ± 2.0	96.0 ± 2.5
Pubertal Development	3.4 ± 0.4	3.4 ± 0.5

Table 7: Posture Variable Group Means (Mean ± SD)

	Swimmers	Non-overhead athletes
Forward Head Posture (°)	36.1 ± 4.2	34.9 ± 4.0
Forward Shoulder Posture (°)	45.1 ± 10.9	46.6 ± 8.5

Table 8: Physical Characteristic Group Means (Mean ± SD)

	Swimmers		Non-overhead athletes	
	Dom	*NDom*	*Dom*	*NDom*
Normalized Pec Minor Length (% of height)	7.6 ± 1.0	7.5 ± 0.9	7.1 ± 0.7	7.2 ± 0.6
Normalized Subacromial Space (% of height)	1.2 ± 0.2	1.2 ± 0.3	1.1 ± 0.1	1.0 ± 0.2
IRROM (°)	55.5 ± 9.5	56.2 ± 6.7	55.2 ± 6.9	51.2 ± 7.7
ERROM (°)	108.06 ± 12.3	105.7 ± 11.5	109.1 ± 9.1	103.5 ± 7.3
Posterior Shoulder Tightness (°)	18.9 ± 4.7	18.2 ± 4.9	24.3 ± 4.4	21.4 ± 4.9

There were no significant differences in forward head posture (*p=0.22)* or forward shoulder posture (*p=0.60)* between swimmers and non-overhead athlete when measured pre-training season. There was a significant group-by-limb interaction for pectoralis minor length ($F_{1,73}$=5.60, *p=0.02)* with a significant main effect for group ($F_{1,73}$=5.72, *p=0.045)* with swimmers presenting with significantly longer normalized pectoralis minor lengths when collapsed across limbs. There was no main effect for limb when collapsed across groups (*p*=0.72). There was a significant group-by-limb interaction for subacromial space distance ($F_{1,73}$=5.2, *p=0.03)* with a significant main effect for group ($F_{1,73}$=7.63, *p=0.01)* with swimmers presenting with significantly greater subacromial space distances when collapsed across limbs. There was no main effect for limb when collapsed across groups (*p*=0.34). Although there was a statistically significant difference in normalized pectoralis minor length and subacromial space distance, the mean difference between the values of swimmers and non-overhead athletes is not clinically significant, as it represents less than a 0.4% and 0.06% of body height, respectively. The differences between the groups on pectoralis minor length and subacromial space distance are below the minimum detectable differences, as calculated during pilot testing.

There was not a significant group-by-limb interaction for posterior shoulder tightness ($F_{1,73}$=3.11, *p*=0.08*)*, however there were main effects for both group ($F_{1,73}$=18.44, *p*<0.001)*)* and limb ($F_{1,73}$=7.66, *p*=0.007*)*. Swimmers presented with approximately 4.1° more posterior shoulder tightness than non-overhead athletes when collapsed across limbs. The dominant limb presented with approximately 1.5° more posterior shoulder tightness than the non-dominant limb when collapsed across groups. The differences in posterior shoulder tightness between the groups were less than the minimum detectable differences as calculated during pilot testing. Although statistically significant, these findings may lack clinical significance. There was not a significant group-by-limb interaction for external rotation ROM ($F_{1,73}$=2.3, *p*=0.13*)* and no main effect for group (*p*=0.867), but there was a significant main effect for limb ($F_{1,73}$=14.7, *p*<0.001*)* with the dominant limb presenting with approximately 3.7° greater external rotation ROM on the dominant limb compared to the non-dominant limb. There was a significant group-by-limb interaction for internal rotation ROM ($F_{1,73}$=5.3, *p=0.03)* , but there was no main effect for group (*p*=0.09) or limb (*p*=0.11).

To evaluate changes in physical characteristics over the training season (*Specific Aim 1)*, seventy-five participants were screened for participation in the research study (44 competitive swimmers and 31 non-overhead athletes). Over the 12-week training season, there was a 97% retention rate for swimmers. One swimmer withdrew from the study due to shoulder pain, which resulted in surgery. There was a 94% retention rate for non-overhead athletes. Two non-overhead athletes withdrew: one due to illness that lasted for longer than 2 weeks that caused missed participation and one due to illness on the days of the second testing session. Therefore, there were a total of 72 participants included in the analysis of changes that occurred over the course of the training season. Demographics for participants who were tracked over the 12 weeks are included in **Table 9.** Mean change scores for each variable are presented in **Table 10.**

Table 9: Demographics for participants who were tracked for 12 weeks

	Swimmers	Non-overhead Athletes
n	43 (25F; 18M)	29 (19F; 10M)
Age (yrs)	16.5 ± 1.0	16.5 ± 1.1
Height (cm)	172.3 ± 13.0	169.3 ± 8.2
Mass (kg)	66.2 ± 10.3	57.9 ± 8.4

Table 10: Mean Change Scores of Physical Characteristic Variables

	Swimmers		Non-overhead athletes	
	% Change Pre-6 weeks	*% Change Pre-12 weeks*	*% Change Pre-6 weeks*	*% Change Pre-12 weeks*
Forward Shoulder Posture	17.5 ± 17.6	14.9 ± 19.3	0.4 ± 8.6	0.8 ± 11.8
Forward Head Posture	1.4 ± 11.1	7.2 ± 13.7	2.7 ± 9.6	6.0 ± 8.3
Dominant Subacromial Space Distance	-5.9 ± 6.0	-10.7 ± 11.7	-1.2 ± 0.9	1.5± 13.0
Non-Dominant Subacromial Space Distance	-5.5 ± 11.6	-11.7 ± 14.8	2.9 ± 0.9	5.7 ± 17.0
Dominant Pectoralis Minor Length	2.6 ± 9.0	0.7 ± 8.8	-2.7 ± 13.5	-0.5 ± 10.3
Non-Dominant Pectoralis Minor Length	3.7 ± 8.2	1.79 ± 8.1	-4.6 ± 11.8	-2.4 ± 9.5

There was a significant main effect for group for forward shoulder posture ($F_{1, 70}$=19.84, p<0.001). Swimmers demonstrated significantly greater increases in forward shoulder posture compared to non-overhead athletes **(Figure 8)**. There was no significant main effect of time (p=0.38*)* and no significant group by time interaction (p=0.24*)* for forward shoulder posture. Swimmers forward shoulder posture increased by approximately 15% over the course of the training season, while non-overhead athletes only increased by approximately 1%. There was a significant main effect of time for forward head posture ($F_{1, 70}$=13.2, p=0.001). All participants moved into significantly more forward head posture over the course of the study **(Figure 9).** There was no significant main effect of group (*p*=0.98*)* or group by time interaction for forward head posture (*p*=0.31*).*

Figure 8: Forward Shoulder Posture Changes

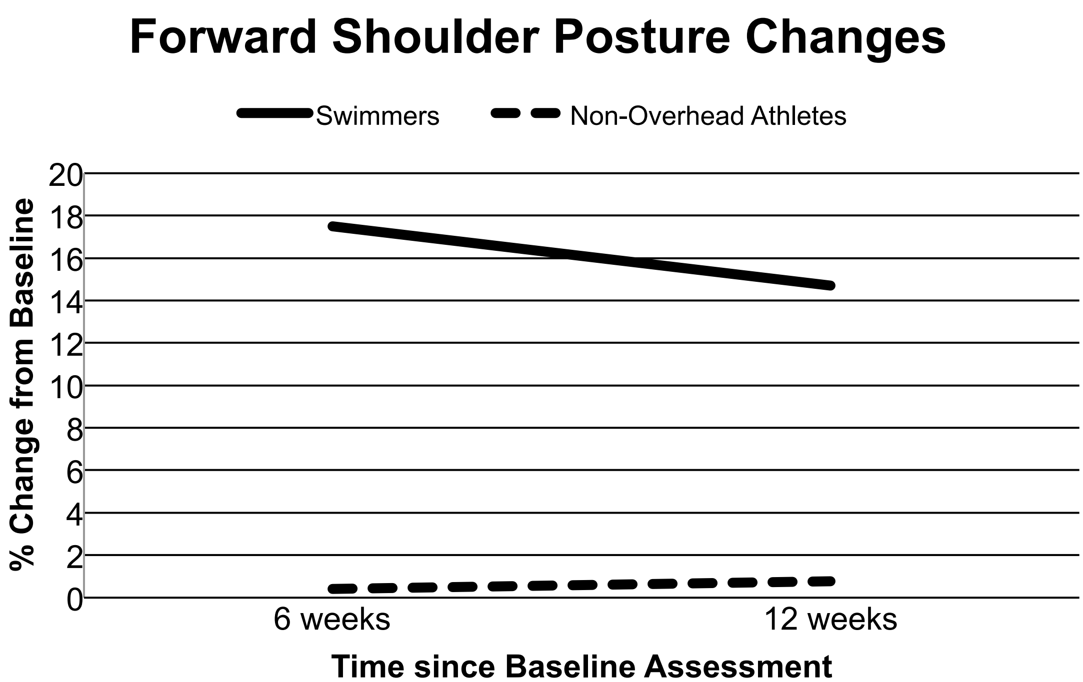
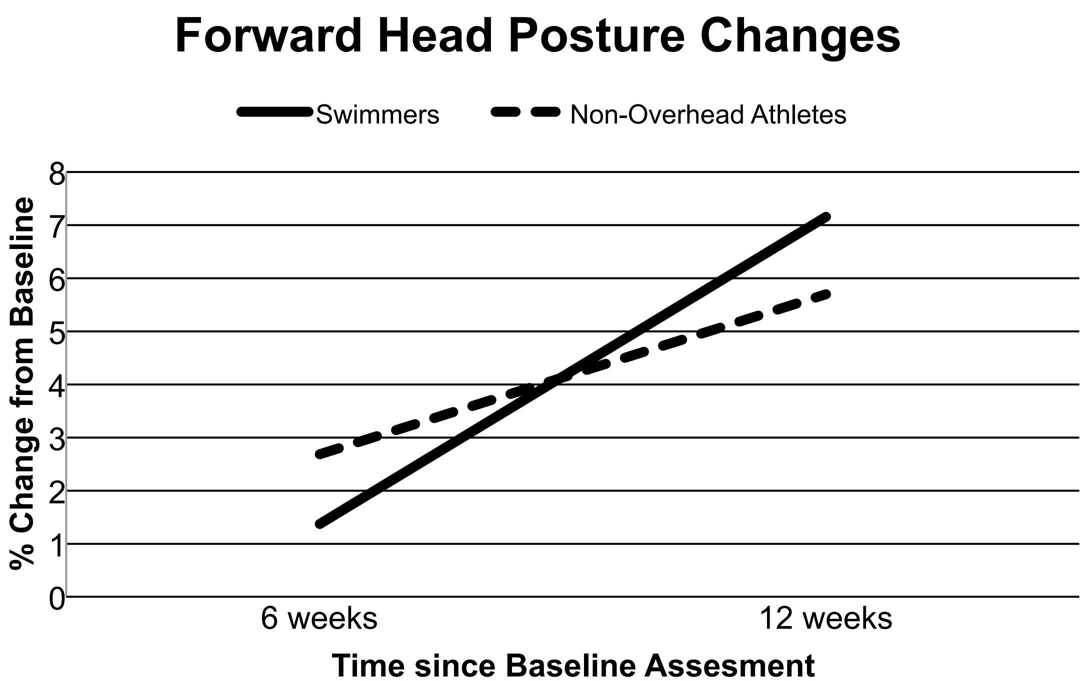
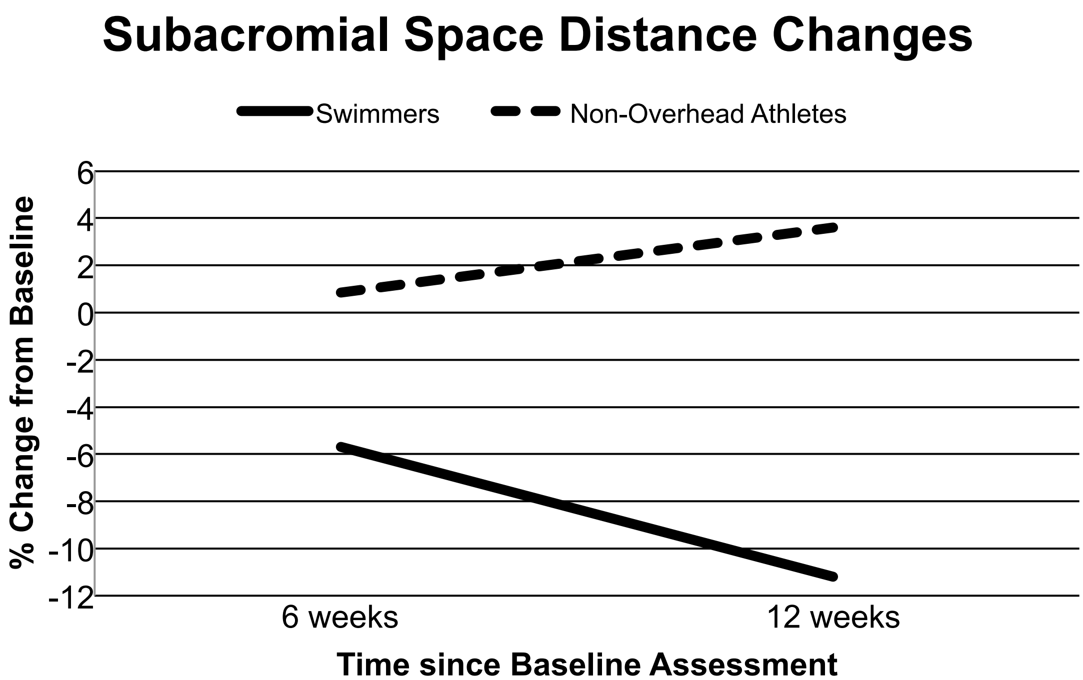


Figure 9: Forward Head Posture Changes



There was a significant group-by-time interaction in percent change scores for subacromial space distance ($F_{1, 70}$=9.83, *p*=0.003) **(Figure 10)**. There was a significant main effect for group, as swimmers had significantly greater decreases in subacromial space distance than non-overhead athletes over the course of the training season ($F_{1, 70}$=26.03, *p*<0.001), but no main effect for time (*p*=0.50). Over the course of the training season, swimmers subacromial space distance decreased by 8.5%, while non-overhead athletes subacromial space distance slightly increased by 2.5%. There was not a significant limb-by-time-by group (*p*=0.65) or limb-by-time (*p*=0.68) interaction and no main effect of time (*p*=0.30) or limb (*p*=0.18) for changes in subacromial space distance over the training season.

Figure 10: Subacromial Space Distance Changes

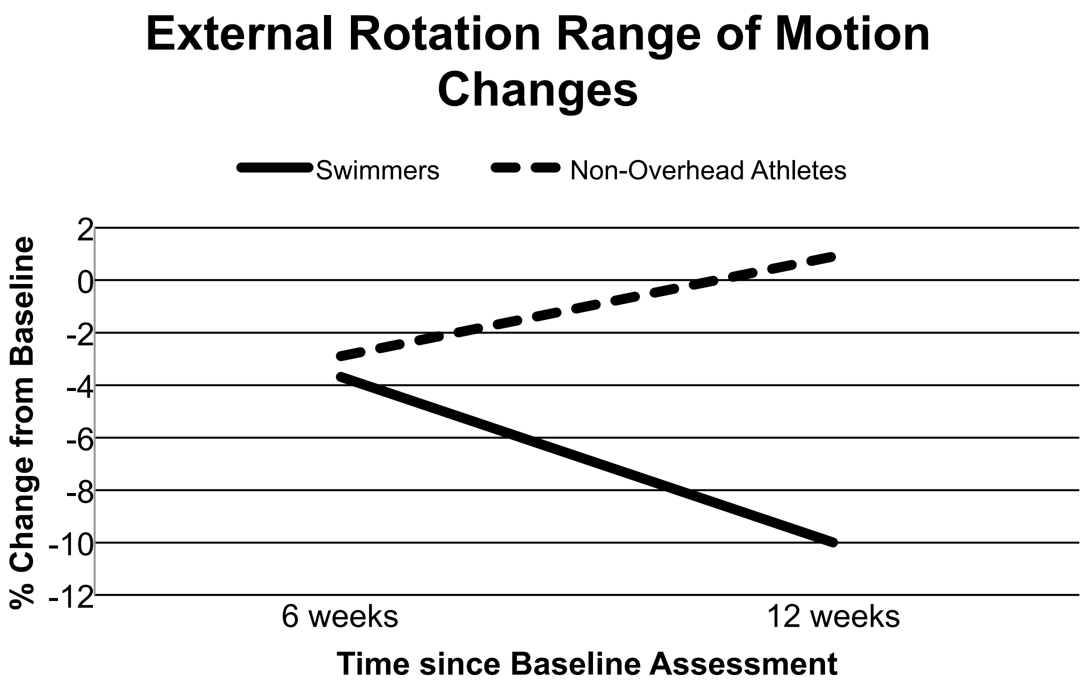


There was a significant group-by-time ($F_{1, 70}$=5.70, *p*=0.02) and group-by-limb interaction for percent change of pectoralis minor length, but no significant main effect of time (*p*=0.89), limb (*p*=0.31), or group (*p*=0.12). The limb-by-time-by-group interaction was not significant (*p*=0.90).

There was a significant fair to moderate relationship between changes in forward shoulder posture and changes in dominant normalized subacromial space distance (r_{68}=-0.49, *p*<0.001) and changes in forward shoulder posture and changes in non-dominant normalized subacromial space distance (r_{68}=-0.47, *p*<0.001) from the baseline testing session to the assessment 6-weeks following baseline assessment. As forward shoulder posture increased, both dominant and non-dominant subacromial space significantly decreased. Correlations between changes in pectoralis minor muscle length and forward shoulder posture and subacromial space distance were not significant.

There was a significant group-by-time interaction in percent change scores for external rotation ROM ($F_{1, 70}$=51.82, *p*<0.001) **(Figure 11)**. There was a significant main effect for group, as swimmers had significantly greater decreases in external rotation ROM than non-overhead athletes over the course of the training season ($F_{1, 70}$=25.29, *p*<0.001) and main effect for time ($F_{1, 70}$=35.89, *p*<0.001), but no main effect for limb (*p*=0.29). During the first 6-weeks of the training season, swimmers had a 3.7% decrease in external rotation ROM, followed by a 7% decrease in external rotation ROM during the next 6 weeks, resulting in a 10% total decrease in external rotation ROM in adolescent swimmers during the training season. This compares to non-overhead athletes who experienced a 2.9% decrease in external rotation ROM during the first 6 weeks, followed by a 3% increase during the next 6 weeks, resulting in a total increase of approximately 1% from the initial screening. The limb-by-time-by-group interaction was not significant (*p*=0.290).

Figure 11: External Rotation Range of Motion Changes



There was a significant group-by-time ($F_{1,70}$=5.38, p=0.02) for percent change of internal rotation ROM , but no significant main effect of time (p=0.82), limb (p=0.12), or group (p=0.46). The limb-by-time-by-group interaction was not significant (p=0.90). There was no significant group-by-time interaction in percent change scores for posterior shoulder tightness ($F_{1, 70}$=0.05, p=0.83), with no main effect for time (p=0.70) or group (p=0.25). There was a main effect for limb ($F_{1, 70}$=19.08, p=*0.001*) with the dominant limb experiencing greater increases in posterior shoulder tightness when collapsed across groups and times. The limb-by-time-by-group interaction was not significant (p=0.48).

Descriptive statistics for reported pain and pain medication use for the competitive swimmers are reported in **Table 11.** There were no significant interactions between limb and time or main effects for limb or time on any of the pain scales, indicating that there was not a significant change in reported pain levels during the course of the training season on any variable. P-values for the interaction and main effects are reported in **Table 12** and grand means of pain scores during the training season (collapsed for limb and time) are reported in **Table 13.**

Table 11: Percent of Swimmers Reporting

	Baseline – 6 weeks post	6 weeks post – 12 weeks post
Mild Pain	70.5%	52.3%
Moderate Pain	31.8%	15.9%
Severe Pain	9.1%	4.5%
Shoulder Injury	2.2%	0%
Pain Medication Use	56.8%	43.2%

Table 12: Limb-by-Time Interaction and Main Effects on Changes in Pain Scores

	Limb-by-Time interaction	Time Main Effect	Limb Main Effect
OSS	0.34	0.61	0.87
SPADI	0.42	0.61	0.81
PENN	0.09	0.07	0.77
FASS	0.72	0.40	0.54

Table 13: Summary of Pain Scores

	Grand Mean	% Disability
OSS *(0-4 scale)*	2.0 ± 2.6	9.3%
SPADI *(0-130 scale)*	4.4 ± 6.5	3.4%
PENN *(0-100 scale)*	4.5 ± 6.8	4.5%
FASS *(24-120 scale)*	29.0 ± 7.6	5.2%

Specific Aim 1 Summary

There were no clinically significant differences in swimmers and non-overhead athletes on forward head and shoulder posture, normalized pectoralis minor length, normalized subacromial space distance, internal/external rotation ROM, and posterior shoulder tightness. These findings indicate that many physical characteristics that are observed in swimmers are not swimming specific. Factors other than swimming participation, such as school and technology use, play an important role in the adaptation of physical characteristics. These findings highlight the importance of interventions during the school day and personal time to improve posture. Because competitive swimmers are also exposed to high levels of training that might further create adaptations in physical characteristics during periods of heavy training, strengthening and stretching programs should be included prior to the training season to help allow swimmers to manage the demands of training, prevent changes in physical characteristics, and ultimately decrease the risk of shoulder injury in competitive swimmers.

Due to the training load, swimmers experienced a significant decrease in subacromial space distance and external ROM and a significant increase in forward shoulder posture, potentially making the athlete more vulnerable to the development of shoulder pain and injury. Over the course of the training season, swimmers develop risk factors that may be causative of impingement and the development of swimmer's shoulder. These findings indicate the importance of implementing an injury prevention program in competitive swimmers designed to strengthen the posterior scapular stabilizing musculature and stretch the anterior musculature. Improvements in these areas would improve scapular functioning and control,[126,130] thus improving subacromial space distance and forward shoulder posture and ultimately decreasing shoulder pain and injury in competitive swimmers. The findings of this study also highlight the importance of understanding the role of participation factors in contributing to changes in physical characteristics and future studies that focus on maximizing performance while minimizing injury risk.

4.2 Specific Aim 2

Specific Aim 2 Results

In order to address specific aim 2, mean participation values for the training season were calculated **(Table 14)** and correlations between changes in physical characteristics and pain scores were calculated.

Table 14: Mean Participation Values During the Training Season

	Baseline – 6 weeks post	6 weeks post – 12 weeks post	Total Training Season
Practices/Week	6.8 ± 1.1	6.6 ± 1.0	6.7 ± 1.0
Yards/Practice	6,181 ± 1,073	5,709 ± 1,225	5,948 ± 1,169
Yards/Week	42,068 ± 11,335	37,732 ± 10,082	39,925 ± 10,892
Total Yards	252,409 ± 68,010	226,395 ± 60,492	477,419 ± 103,829
Dry-land/Week	4.0 ± 1.0	3.3 ± 1.7	3.6 ± 1.6

There were not significant correlations between the variables that changed significantly in the swimmers during the training season (External rotation ROM, Forward shoulder posture, and subacromial space distance). P-values for the correlations are reported in **Table 15.**

Table 15: Correlations between changes in physical characteristics and training volume

	Baseline-6 weeks yardage r (*p*)	6-12 weeks yardage r (*p*)	Total training season yardage r (*p*)
External Rotation ROM	0.20 (*0.06*)	-0.09 (*0.39*)	0.12 (*0.28*)
Forward Shoulder Posture	0.05 (*0.70*)	0.07 (*0.67*)	-.110 (*0.48*)
Subacromial Space Distance	0.05 (*0.65*)	-0.03(*0.78*)	0.11 (*0.30*)

There was a significant correlation between total yardage performed during the training season and SPADI scores (r_{84}=0.34, p=0.002) and total yardage and

PENN scores (r_{84}=0.37, p<0.001). This finding demonstrates that as total yardage increased, so did SPADI and PENN scores- indicating greater shoulder pain and disability over the training season as measured by these scales. There were no significant correlations between yardage completed during the first 6-weeks of the training season and the OSS (p=0.75), SPADI (p=0.37), PENN (p=0.19), and FASS (p=0.56). There were no significant correlations between total yardage and OSS (p=0.19) and FASS (p=0.13).

Specific Aim 2 Summary

In the current study, swimmers swam approximately 42,000 yards per week in the first 6 weeks of the training season and 38,000 yards per week during the second 6 weeks of the training season. Previous studies have indicated that swimmers take an average of 15 strokes per 25 yards,[40] which would indicate that these club swimmers experience 11,400-12,600 shoulder revolutions per arm per week while completing their swim training. This high level of training may be the cause of the majority of swimmers reporting shoulder pain during the course of the training season with moderate amounts of disability. Further, significant correlations between total yardage during the training season and SPADI and PENN scores at the post-training season were observed. As there was an increase in total yardage performed during the training season, there was an increase in the total SPADI and PENN scores indicating greater reported pain and disability. These findings highlight the importance of training demands on the development of shoulder pain and disability and are in agreement with previous research evaluating the effect of yardage on swimmers pain and dysfunction.[8] On exam, swimmers with supraspinatus tendinopathy and pain have previously been found to have greater supraspinatus tendon thickness values that were associated with the number or hours swam and amount of yardage completed per week, indicating that the volume of training is related to the development of shoulder pain and injury.[8] It is relevant to acknowledge that the PENN and SPADI are not swimming (or sport) specific scales as the PENN only has 2 questions about ability to perform sport and the SPADI has no questions regarding sport participation.

While the majority of swimmers reported pain during the training season when asked, significant pain, functioning and dissatisfaction were not able to be identified using the subjective shoulder scales of pain and functioning (OSS, SPADI, PENN, and FASS). These tools were originally selected to track changes in pain and satisfaction over the course of the training season because they have previously been found to be valid tools for use in pathological populations and for identifying changes in symptoms and functioning.[197,200,201,203] Although most of the swimmers in the current study were experiencing pain during the training season, they were not a true pathological population with a diagnosed injury. Further, participants in the current study were participating with no severe limitations during the training season. The participants were participating in swimming at high levels, thus may not have had limitations in functioning in daily living, which were primarily the questions on the OSS, PENN, and SPADI. We did not observe a relationship between the swimming specific scale (FASS) and training volume, which may be because they participants were not limited in their swimming participation. The majority of the questions on the FASS asked about limitations in the ability to perform each stroke, dry land, and practice time. As inclusion criteria for this research study, participants could not have limitations on these specific components. Lack of significant findings based on these scales may be due to a selection bias and may not be reflective of pain, disability, and dissatisfaction that the swimmers are experiencing during the training season. Finally, the scales have predominantly been used in an adult population. The limitations that are questioned about in these scales may not be applicable in an active, adolescent population. In order to better address shoulder pain in adolescent swimming, an age and sport specific questionnaire should be developed for clinicians, coaches, and parents to use to track pain and limitations over the training season.

Although there were significant changes in forward shoulder posture, subacromial space distance, and external rotation ROM during the training season, none of these variables were correlated to training volume. In addition to training volume, other extrinsic factors such as rest and recovery, training intensities, and equipment use during training may also be significant contributors to changes in physical characteristics and shoulder pain during the training season.

The findings of the current research study, and discussion of these, highlight the interplay of the intrinsic and extrinsic factors that may contribute to shoulder pain and injury in competitive swimmers. Alterations in the intrinsic risk factors may alter stroke biomechanics and/or participation variables such as yardage, equipment use, intensity of practice and these extrinsic risk factors may alter the intrinsic risk factors increasing shoulder stress. Overtime, this stress results in the development of swimmer’s shoulder, characterized by shoulder pain and dysfunction. Due to shoulder pain, alterations in technique and physical characteristics may occur and as swimmers continue to train through this, they enter a cycle of continuous shoulder pain. It is important to understand each intrinsic and extrinsic risk factor and how it may influence other risk factors in order to provide evidence to help coaches and clinicians in designing training schedules and practices, as well as injury prevention programs.

4.3 Future Research

The findings of this study indicate changes in physical characteristics that occur over the training season, as well as relationships between total yardage and changes in pain and physical characteristics. While significant correlations between total yardage and SPADI and PENN scores were observed, total yardage only explained 11% of the total SPADI score and 14% of the total PENN score. In addition, there were no significant relationships between the changes in physical characteristics and the 6-week total yardages and training season total. It is important for future research to identify other extrinsic factors that may be the driving factor behind changes in physical characteristics and explain additional variance in the pain scores. Future studies should attempt to evaluate changes in physiological variables following training, recovery factors, training intensities, and equipment use during training to gain a better understanding of how participation factors are influencing the development of shoulder pain, as well as alterations in physical characteristics of competitive adolescent swimmers. This research would aid in the development of evidence-based participation guidelines that could maximize performance while decreasing injury risk.

The physical characteristics and sport specific demands of swimmers are different than any other sport; therefore sport specific dry-land, weight training, and injury prevention programs are needed. Implementation of an evidence based exercise program tailored for swimmers may decrease the stress on the shoulder and may prevent shoulder pain. Additionally, a prospective study assessing the effectiveness of an intervention program in reducing the risk of shoulder injury is needed. Prospective research is needed to determine if an intervention program can prevent changes in physical characteristics and shoulder pain/injury during the training season. Finally, research examining shoulder injuries and prevention programs in swimmers of all ages is necessary. Implementing an intervention program in youth swimmers may have a greater impact on the developing muscles and decrease shoulder pain and injuries and may promote physical characteristics that prevent shoulder injuries from developing later in their careers.

4.4 Limitations

There are several limitations that should be acknowledged. The swimmers selected for participation in this research study were training at the highest level on their swim team. These findings may not be applicable to swimmers on lower-level teams who experience significant less training demands. There are several limitations related to the participation tracking. First, participation was self-report and verified by the coaches, but was not observed for each swimmer. This could have led to some inaccuracy in calculation of participation variables. In addition, the effort that each participant put into training could not be assessed. While this was not something that could be evaluated by the research team, the coaches, as part of their normal job responsibility, always encouraged athletes to give maximal effort and spoke individually with athletes that did not appear to be training as hard to change the behavior. Finally, we did not control for activities outside of team participation, however no participants from our study were members of another sport team. We did not control for activity such as physical education class or workouts outside of swimming training.

There are several limitations regarding the posture and subacromial space distance measurements. It is possible for the athlete to consciously correct posture, which would also modify subacromial space distance. During this study, participants were asked to squat three times before the posture picture was taken and then instructed to stand comfortably. This method was used to distract the participants from the purpose of the picture and from observation the participants were not self-correcting their posture. During the ultrasound images of subacromial space distance, the only instruction was to sit comfortably with their arms on their lap. We did not correct or try to influence posture. Again, observationally, participants were in a comfortable, natural posture and not self-correcting. It is also important to acknowledge that the measurements used for the assessment of subacromial space occurred at 0° of abduction with no muscle activation; thus subacromial space changes may be different in greater degrees of abduction or during an active task.

4.5 Conclusions

The significant changes in the physical characteristics that are seen in competitive swimmers during the training season compared with changes in non-overhead athletes and the relationships between total yardage and pain scores indicate that the training season clearly has a substantial influence on physical characteristics that may lead to shoulder pain and injury. These findings highlight the interplay of intrinsic and extrinsic risk factors that may be occurring. The development of shoulder pain and injury in swimmers is multifactorial due to a combination of both intrinsic and extrinsic risk factors. When athletes present with certain intrinsic risk factors, they become predisposed to injury. However, without exposure to extrinsic risk factors (participation factors), the athlete is unlikely to develop an overuse injury. With the presence of extrinsic risk factors, the athlete is susceptible to the development of shoulder pain and injury. Through repeated exposures, without the presence of a diagnosed injury, the modifiable intrinsic risk factors that swimmers are continually changing due to adaptations of the shoulder during swim training. These adaptations and exposure to extrinsic risk factors may cause the susceptible athlete to develop shoulder pain or injury. Future research needs to focus on understanding each of intrinsic and extrinsic risk factors and the relationships between them in order to created evidence-based swim training, dry-land, weight training, and injury prevention program that maximize performance while minimize injury risk.

Manuscript 1

Comparison of Upper Extremity Physical Characteristic between Adolescent Competitive Swimmers and Non-Overhead Athletes

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Context: Poor posture and associated physical characteristics may be an observation that is seen in both competitive swimmers and non-overhead athletes due to the influence of factors other than swimming participation. It is important to understand if alterations in posture and associated physical characteristics occur as a result of sports training or factors other than swimming participation to better understand injury risk and possible interventions.

Objectives: To compare posture, subacromial space distance, pectoralis minor length, and glenohumeral range of motion (ROM), which consisted of external rotation, internal rotation, and horizontal adduction, between adolescent competitive swimmers and non-overhead athletes to determine if the common profile in swimmers is due to swimming participation or if this profile may be due to lifestyle factors.

Evidence Acquisition: 45 competitive adolescent swimmers and 31 non-overhead athletes that were not currently experiencing any shoulder, neck, or back pain that limited their participation in sports activity were included in the study. All participants were evaluated one time prior to the start of the training season for competitive swimmers. At the testing session, data collection occurred prior to the start of team practice and participants completed a physical exam that included evaluation of posture, pectoralis minor length, subacromial space distance, and glenohumeral ROM.

Evidence Synthesis: There were no clinically significant differences in swimmers and non-overhead athletes on posture, normalized pectoralis minor length, normalized subacromial space distance, as well as external and internal rotation ROM. Swimmers presented with significantly less horizontal adduction ROM than non-overhead athletes.

Conclusions: These findings indicate that factors other than swimming participation, such as school and technology use, play an important role in the adaptation of physical characteristics of adolescents. It is important to consider factors other than swimming participation to understand injury risk and injury prevention strategies in competitive swimmers.

Key Words: Swimmers, Subacromial Space Distance, Range of Motion, Posture

Word Count: 291/300

Introduction

Currently there are over 300,000 competitive club swimmers in the United States with 43.5% of the members are between the ages of 13-18 on elite teams.[1] These club swimmers are exposed to tremendous training loads, performing between 42,000-49,000 yards per week (over approximately 7 practices) in addition to dry-land and weight training.[2] Due to this tremendous training load, shoulder pain is the most common musculoskeletal complaint that is experienced in competitive swimmers.[3-5] Interfering shoulder pain has been reported in 45-91% of swimmers during their careers.[6-8] Shoulder pain in swimming is a major cause of missed practice and slower swim times[3] and may develop as a result of the fact that 90% of propulsive force in swimming comes from the upper extremity because the athlete must pull the body over the arm through the water.[7] The high volume of swim training is hypothesized to contribute to alterations in the physical characteristics as the upper quarter adapts to the demands that are placed on it and predispose them to the development of "swimmer's shoulder," which is the general term for overuse injury in swimming athletes, which includes subacromial impingement, rotator tendinosis, and biceps tendinosis.[7-10]

Anecdotally, swimmers are notorious for having poor posture.[9] Swimmers are characterized as having forward head, rounded shoulders and increased thoracic kyphosis, which can affect scapular kinematics, subacromial space distance, pectoralis minor length, and glenohumeral range of motion (ROM).[11-14] Altered muscle lengths that develop due to the demands of training commonly cause postural deviations such as forward head and forward shoulder posture. Forward head posture can be due to tight suboccipital muscles and upper trapeziums coupled with weak deep neck flexors. [15] Forward shoulder posture can be due to tight pectoral muscles coupled with weak middle and lower trapezius.[15]

Faulty postural alignment over time can lead to abnormal stress on tissues that may contribute to shoulder pain.[15] Muscle imbalances may alter biomechanics and ROM and contribute to secondary impingement, joint instability, and fatigue. Alterations in scapular kinematics and decreased muscle strength associated with a slouched, forward shoulder posture[11] have been theorized to decrease the subacromial space distance, thus increasing the risk of impingement.[16-21] A decrease in subacromial space, identified using diagnostic ultrasound, has been found on the affected shoulder of individuals with impingement syndrome when compared to asymptomatic controls.[22] The decrease in subacromial space in individuals with impingement syndrome may occur due to a loss of scapular control, as it has been found that tennis players with scapular dyskinesia have significantly smaller subacromial space distance than individuals who do not have scapular dyskinesia.[19] Altered scapular kinematics that are related to subacromial impingement have also been linked with a shortened pectoralis minor length which would contribute to the a narrower subacromial space width.[23]

Alterations is postural alignment may be due to muscle imbalances,[15] which clinically may present as altered ROM. Swimmers have decreased internal rotation ROM compared to controls.[8,24] Hypertrophic changes, caused by the accumulation of large distraction forces placed on the shoulder during swimming, may cause thickening of the posterior glenohumeral capsule, which has been correlated with lesser humeral rotation ROM among baseball players.[25] Previous research has identified alterations in external ROM as one of the primary risk factors for the development of interfering shoulder pain and injury in competitive swimmers.[26] Swimmers with limited external rotation (<93°) and excessive external rotation (>99°) ROM were found to be more likely to develop interfering shoulder pain and more likely to sustain a serious shoulder injury than those in the reference group (93-99° external rotation ROM).[26]

While youth swimmers are exposed to high training demands that may affect their posture, poor posture (and associated physical characteristics) may be an observation that is seen in both competitive swimmers as well as the general student population who are non-overhead athletes. Laptop computer use, [27] backpack carrying[28] and study hours all contribute to poor posture in the student population.[29] Alterations in posture may be present in both competitive swimmers and non-overhead athletes due to the influence of factors other than swimming participation. It is important to understand if alterations in posture and associated physical characteristics occur as a result of sports training or factors other swimming participation to understand injury risk and possible interventions. Therefore, the purpose of this study was to compare posture, subacromial space distance, pectoralis minor length, and glenohumeral ROM, which consisted of external rotation, internal rotation, and horizontal adduction, between competitive adolescent swimmers and non-overhead athletes.

Methods

A cross-sectional research design with a competitive swimming group and non-overhead athlete group was utilized in the current study. All participants were evaluated one time prior to the start of the training season for competitive swimmers. At the testing session, data collection occurred prior to the start of team practice and participants completed a physical exam that included evaluation of posture, pectoralis minor length, subacromial space distance, and glenohumeral ROM.

Participants

Participants were recruited for both a swimming group and a non-overhead athlete group. Participants were both males and females between the ages of 13 and 18 years old.

Swimming participants were included in the research study if they met all of the following criteria: member of a senior (top training level) team on their club team, regularly trained at least 4 times per week, 1-2 hours each practice session and were not currently experiencing back, neck or shoulder pain that limited their ability to participate. Swimming participants were excluded from the research study if they met the following criteria: had less than 2 years of competitive swimming experience, were currently using any type of external, correctional posture device, or had a history of shoulder surgery.

Non-overhead athletes were recruited from local high schools and soccer, track, and cross-country leagues. Non-overhead athlete participants were included in this research study if they: had not participated on an organized team of an overhead dominant sport for more than 1 year (e.g. baseball, softball, tennis, volleyball, swimming) and were not experiencing back, neck, or shoulder pain that limited participation during the course of the study. Non-overhead athlete participants were excluded from this research study if they: had a history of shoulder surgery, currently experiencing any shoulder, neck, or back pain that limits their ability to participate in activity, or currently using any type of external, correctional posture device.

Procedures

Prior to data collection, the primary investigator met with all potential participants and distributed information packets regarding the research study. Those interested in participating and their parents/guardians read and signed the informed consent form approved by a University Institutional Review Board. After completion of the consent forms, participants completed a demographics form that included questions about years of experience, event specialization, practice requirements and previous injury history. All forms were collected at the beginning of the testing session. Participants were allowed to do their typical warm-up and then rotated through the testing stations.

Reflective markers were placed on the dominant side of each participant on the following anatomical landmarks: tragus, C7, and anterior tip of the acromion.[30] While standing in front of a horizontal reference line, participants performed 3 overhead squats and then were instructed to stand in "a relaxed position" while a picture was taken in the sagittal plane. Postural analysis was performed by the primary investigator using Image J software (National Institute of Health, Bethesda, MD). The landmarks were digitized to calculate the forward head angle- defined as the angle of inclination of the line extending from C7 to tragus and the vertical line and the forward shoulder angle- defined as the angle of inclination of the line extending from C7 to the shoulder and the vertical line **(Figure 1)** for each participant. A three-trial mean was calculated for each posture variable. Prior to data collection, strong intrasession reliability and precision were demonstrated for forward head posture (ICC= 0.981 SEM=0.73°) and forward shoulder posture (ICC= 0.992 SEM=0.88°)

Subacromial space distance was measured using a portable diagnostic ultrasound machine (LOGIQe, General Electric, Milwaukee, Wisconsin, USA) The participant was assessed while seated in a chair with their forearm resting on his/her thigh in pronation. Sound coupling gel was applied to the ultrasound transducer, which was then placed in the coronal plane of the shoulder **(Figure 2A)**. When the lateral acromion and humeral head could clearly be visualized, the image was saved for later analysis. [31] Three trials were performed bilaterally. After the measurements were taken, a research assistant re-labeled the stored images, so that the primary investigator who was evaluating the subacromial space distance was blinded to group assignment. Once all data collection was completed, the primary investigator measured subacromial space distance using Image J software. Subacromial space distance was defined as the shortest distance between the anterior-inferior tip of the acromion and the humeral head **(Figure 2B)**.[32] A three trial mean was taken for each side. Subacromial space distance was normalized to height and normalized subacromial space distance was used as the dependent variable. Prior to data collection, strong intrasession reliability and precision were demonstrated for subacromial space distance (ICC= 0.912, SEM=0.04 cm)

Pectoralis minor length was measured with the participant lying supine on the table. Pectoralis minor muscle length were measured using vernier calipers (Westward Tools, Edmonton, AB, Canada) to measure the distance between the medial-inferior aspect of the coracoid process to the anterior-inferior edge of the 4th rib just lateral to the sternocostal junction **(Figure 3)**.[33] This method of measurement of the pectoralis minor muscle length has been validated using cadavers.[33] A three-trial mean was calculated for pectoralis minor length. Pectoralis minor length was normalized to height and normalized pectoralis minor length was used as the dependent variable. Prior to data collection, strong intrasession reliability and precision were demonstrated for measuring pectoralis minor length (ICC= 0.920, SEM=0.42 cm).

Glenohumeral internal and external rotation ROM were measured passively with a digital inclinometer (The Saunders Group, Inc. Chaska, MN) based on the recommendations of Norkin and White **(Figure 4)**.[34] Participants lay supine on a portable treatment table with 90º of shoulder abduction and elbow flexion. Scapular stabilization was provided by the examiner through a posteriorly directed force at the acromion to isolate motion to the glenohumeral joint. The examiner then passively rotated the limb to end range in internal rotation and external rotation while a second investigator aligned the digital inclinometer with the forearm and recorded the humeral rotation angles. The dependent variables assessed were passive humeral internal rotation, external rotation, and total of arc of humeral motion (°). A three-trial mean was calculated for rotational ROM. Prior to data collection, strong intrasession reliability and precision were demonstrated for measuring internal rotation ROM (ICC= 0.976, SEM=1.36°) and external rotation ROM (ICC= 0.988, SEM=1.2°).

Posterior shoulder tightness was assessed by measuring the amount of glenohumeral horizontal adduction with the participants lying supine on a portable treatment table **(Figure 4)**.[35] The participant's scapula was passively stabilized in full retraction by applying pressure the lateral border of the scapula. The humerus was elevated to 90º abduction and neutral rotation. The humerus was then passively horizontally adducted while the scapula remained fully retracted. At the end ROM, a second examiner aligned the digital inclinometer from the shoulder joint center along the midline of the humerus to measure the humeral horizontal adduction angle. A three-trial mean was calculated for posterior shoulder tightness. Prior to data collection, strong intrasession reliability and precision were demonstrated for measuring horizontal adduction ROM (ICC= 0.910, SEM=1.1°).

Statistical Analysis

Statistical analyses were run using SPSS version 20.0 software (SPSS Inc, Chicago, IL). Descriptive statistics were calculated for each variable. Independent t-tests were used to evaluate differences between forward head and forward shoulder posture in competitive swimmers and non-overhead athletes. Two-way ANOVAs (group-by-limb) were used to evaluate differences in subacromial space distance, pectoralis minor length, and ROM variables. An a priori alpha level of 0.05 was set for all comparisons for statistical significance.

Results

The study participants were 44 competitive adolescent swimmers and 31 non-overhead athletes. Complete participant demographic information is included in **Table 1.** The mean values for forward head posture and forward shoulder posture are presented in **Table 2.** Group means for dominant and non-dominant normalized pectoralis minor length, normalized subacromial space distance and glenohumeral internal rotation, external rotation, and horizontal adduction ROM are presented in **Table 3.**

There were no significant differences in forward head posture (*p=0.22)* or forward shoulder posture (*p=0.60)* between swimmers and non-overhead athletes when measured pre-training season. There was a significant group-by-limb interaction for pectoralis minor length ($F_{1,73}$=5.6, *p=0.02)* with a significant main effect for group ($F_{1,73}$=5.72, *p=0.045)* with swimmers presenting with significantly longer normalized pectoralis minor lengths when collapsed across limbs. There was no main effect for limb when collapsed across groups (*p*=0.72). There was a significant group-by-limb interaction for subacromial space distance ($F_{1,73}$=5.2, *p=0.026)* with a significant main effect for group ($F_{1,73}$=7.63, *p=0.007)* with swimmers presenting with significantly greater subacromial space distances when collapsed across limbs. There was no main effect for limb when collapsed across groups (*p*=0.37). Although there was a statistically significant difference in normalized pectoralis minor length and subacromial space distance, the mean difference between the values of swimmers and non-overhead athletes is not clinically significant, as it represents less than a 0.4% and 0.06% of body height, respectively.

There was not a significant group-by-limb interaction for posterior shoulder tightness ($F_{1,73}$=3.11, p=0.082), however there were main effects for both group ($F_{1,73}$=18.436, p<0.001)) and limb ($F_{1,73}$=7.664, p=0.007). Swimmers presented with approximately 4.1° more posterior shoulder tightness than non-overhead athletes when collapsed across limbs. The dominant limb presented with approximately 1.5° more posterior shoulder tightness than the non-dominant limb when collapsed across groups. There was not a significant group-by-limb interaction for external rotation ROM ($F_{1,73}$=2.3, p=0.132) and no main effect for group (p=0.867), but there was a significant main effect for limb ($F_{1,73}$=14.7, p<0.001) with the dominant limb presenting with approximately 3.7° greater external rotation ROM on the dominant limb compared to the non-dominant limb. There was a significant group-by-limb interaction for internal rotation ROM ($F_{1,73}$=5.3, p=0.025) , but there was no main effect for group (p=0.093) or limb (p=0.114).

Discussion

The purpose of this study was to evaluate the differences in physical characteristics in competitive swimmers and non-overhead athletes to determine if alterations in swimmers physical characteristics are due to training demands or factors other than swimming participation. Comparison between adolescent competitive swimmers and non-overhead athletes will provide valuable information to determine if factors other than swimming participation contribute to postural and physical characteristic abnormalities that may increase the risk of shoulder injury in competitive swimmers. This information will allow clinicians and coaches to create more targeted interventions and suggestions for competitive swimmers.

There were no significant differences between adolescent competitive swimmers and non-overhead athletes on forward head or forward shoulder posture. Despite there being no significant differences, both groups were above previously proposed criteria for an ideal shoulder posture of equal to or less than 22° of forward shoulder angle, as the swimmers demonstrated 45.1° and the non-overhead athletes had 46.6°.[30] While swimmers are often characterized as having a rounded shoulder posture, this presentation may be a common postural deviation present in current high school students. Increased forward shoulder posture has been hypothesized to develop due to tight pectoral muscles coupled with weak middle and lower trapezius.[15] We theorize that forward shoulder posture develops due to weakness of posterior scapular stabilizers, followed by anterior musculature contracture that develops as students sit during class and utilize laptops and/or desktop computers at desks that are not ergonomically advantageous.[36] Over 80% of students today use laptop computers as their personal computers for both school work and personal use.[37] It has been reported that students spend an average of 3.2 hours a day using lap top computers and during laptop use 60% of individuals report discomfort.[27] This discomfort is attributed to postural adaptations that occur over long periods of time while working at the computer. Laptop computers have been shown to increase exposure to risk factors for musculoskeletal disorders due to their compact size, integrated monitor and less than ideal input devices.[37] Because the displays on laptops are not adjustable and most desks are not adjustable, students assume a more forward shoulder and forward head posture in order to view their computers.[29] In addition, it has long been suggested that school desks are not ergonomically advantageous,[38] as students must adjust their posture in order to read paper documents and notes that are sitting on their flattened desks. Recent suggestions for desks include adjustable desk height and angled desks that may improve sitting posture of students.[29,36,39] Based on the results of the current study, it would be recommended that all adolescents focus on improving forward shoulder posture. This could be done through a strengthening and stretching program to address muscular imbalances, improved computer and desk ergonomics, and/or increased emphasis on the importance of posture.

While improving forward shoulder posture is important for most individuals, it is especially important for competitive swimmers. In addition to factors other than swimming participation, swimmers also face muscle length changes due to the repetitive nature of the sport, as swimmers are prone in the water using the anterior musculature, including the pectoral muscles, the serratus anterior and the upper trapezius to generate power in the water.[40] Previous research has identified an effective 6-week stretching and strengthening program in competitive swimmers for correction of forward shoulder posture.[14] This program included: scapular retraction, shoulder external rotation, and shoulder flexion using resistive tubing, as well as stretching the pectoralis minor while laying over a foam roller and the pectoralis major with the individuals hand linked behind their head with a partner applying overpressure into retraction. In addition to incorporating a stretching and strengthening program, the importance of proper postural alignment during school and computer use should be discussed with competitive swimmers, so it can be a point of emphasis throughout their days to improve forward shoulder posture-resulting in improved scapular stabilizing strength and decreased anterior musculature contracture. Together, an intervention program paired with increased awareness throughout the school day could significantly decrease forward shoulder posture and ultimately reduce the risk of injury in competitive swimmers.

Swimmers presented with increased posterior shoulder tightness, represented by significantly less horizontal adduction, compared to non-overhead athletes. The repetitive nature of swimming may cause fatigue of the posterior rotator cuff muscles, which may place more stress on the posterior capsule to maintain joint stability through the swimming stroke.[41] Over time, the distractive stress may cause repetitive microtrauma to the posterior capsule and a fibroblastic healing response resulting in hypertrophy and contracture. A tight and hypertrophied posterior capsule can cause a shift in the arthrokinematics of the glenohumeral joint. Tightness of the posterior capsule, which is known to limit glenohumeral internal rotation, creates an obligate anterior and superior humeral translation during flexion.[42] As athletes with posterior shoulder tightness move into the flexion with external rotation (as seen in the recovery phase of the swimming stroke), there is increased superior-posterior translation of the humeral head.[43-45] These abnormal translations can decrease the acromiohumeral distance and compress the structures within the subacromial space. It may be beneficial for the posterior shoulder tightness of swimmers to be addressed to allow the humeral head to remain centered during dynamic activity, which may help to prevent impingement during the swimming motion. Potential treatments to improve posterior shoulder tightness include stretching exercises to address muscle flexibility,[46,47] joint mobilization to address capsular tightness,[48] and other forms of manual therapy[49] to address neuromuscular abnormality.

There were no significant differences between groups on external rotation ROM. Although there was no difference between the groups, it is important to acknowledge that the swimmers averaged 108° of external rotation ROM on the dominant side and 105° on the non-dominant side. Previous research has determined that swimmers in the high external rotation ROM group (greater than 100°) were 8.1 times more likely to develop interfering shoulder pain and 35.4 times more likely to sustain a serious shoulder injury than those in the reference group (93-99° external rotation ROM).[26] The excessive external rotation ROM can lead to gradual stretching of the capsular collagen over time which may lead to increased anterior capsular laxity.[50] The excessive external rotation ROM that is seen in many swimmers, may be a result of abnormal stroke mechanics such as dropped elbow during the recovery phase of the freestyle stroke and dropped elbow during the pull through phase of the freestyle stroke.[51] These stroke errors may push the arm into excessive external rotation ROM and increase anterior capsule laxity. Coaches should ensure that they are assessing stroke mechanics regularly, as alterations in mechanics may lead to the development of physical characteristics that promote shoulder injuries.

It is important to acknowledge that the assessment of physical characteristics was performed prior to the start of the training season- a time when competitive swimmers perform a large volume of yardage with high intensity practices in order to gain strength and power.[52] This time period was chosen, as it is the time period when most teams would perform pre-participation screenings. The tremendous training load that swimmers are exposed to may cause muscle fatigue and alterations in physical characteristics that increase the risk of injury during the training season. Previous studies have identified adaptations in scapular kinematics that may promote shoulder impingement over the course of the first 6-weeks of the training season in collegiate swimmers[53] and following a fatigue protocol.[54] Future research should focus on how physical characteristics of swimmers (posture, glenohumeral ROM, pectoralis minor length, and subacromial space distance) change over the course of the training season, as well as how physical characteristics change due to participation variables to better understand injury risk during the training season.

Conclusion

There were no clinically significant differences in swimmers and non-overhead athletes on forward head and shoulder posture, normalized pectoralis minor length, normalized subacromial space distance, and external rotation ROM. Swimmers presented with significantly more posterior shoulder tightness than non-overhead athletes. These findings indicate that factors other than swimming participation, such as school and technology use, play an important role in the adaptation of physical characteristics. In addition to school, competitive swimmers are exposed to high levels of training that may cause alterations in physical characteristics, increasing their risk of injury. Because all adolescents were found to have forward shoulder posture above the ideal posture, it is important to evaluate intervention programs that may help to improve posture in all adolescents. Specific to competitive swimmers, these findings highlight the importance of interventions during the school day and personal time to improve posture, as well as strengthening and stretching programs to decrease the risk of shoulder injury in competitive swimmers.

Figures

Figure 1: Posture Assessment- (A) Forward Head Angle (B) Forward Shoulder Angle

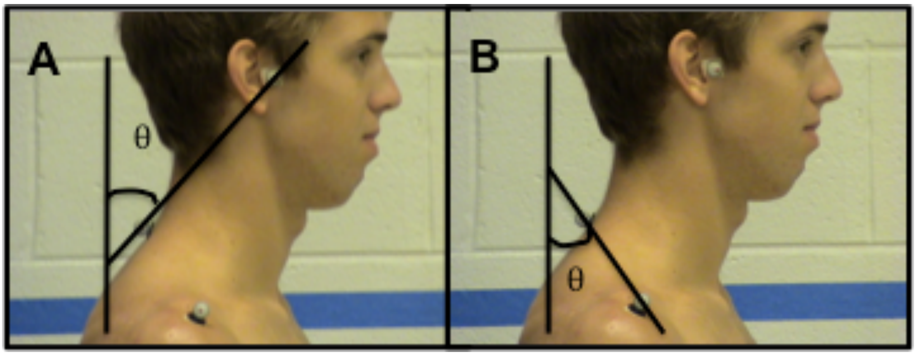

Figure 2: Measurement of Subacromial Space Distance- (A) Subject positioning (B) Ultrasound measurement of subacromial space distance

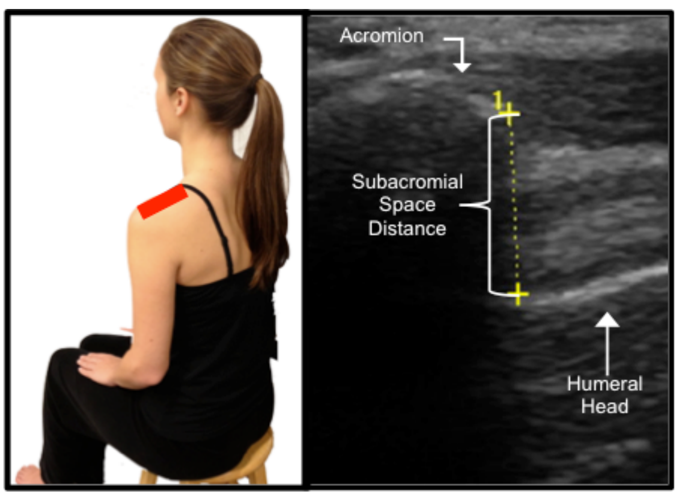

Figure 3: Pectoralis Minor Length Measurement

Figure 4: Range of Motion Assessment- (A) Internal Rotation Range of Motion Measurement (B) External Rotation Range of Motion Measurement (C) Posterior Shoulder Tightness Measurement

Table 1: Participant Demographics

	Swimmers	Non-overhead athletes
n	44 (26F; 18M)	31 (21F; 10M)
Age (yrs)	16.5 ± 1.0	16.5 ± 1.0
Height (cm)	172.2 ± 12.9	168.8 ± 8.4
Mass (kg)	66.2 ± 10.2	57.7 ± 8.2

Table 2: Posture Variable Group Means (Mean ± SD)

	Swimmers	Non-overhead athletes
Forward Head Posture (°)	36.1 ± 4.2	34.9 ± 4.0
Forward Shoulder Posture (°)	45.1 ± 10.9	46.6 ± 8.5

Table 3: Dependent Variable Group Means (Mean ± SD)

	Swimmers		Non-overhead athletes	
	Dom	*NDom*	*Dom*	*NDom*
Normalized Pec Minor Length (% of height)	7.6 ± 1.0	7.5 ± 0.9	7.1 ± 0.7	7.2 ± 0.6
Normalized Subacromial Space (% of height)	1.2 ± 0.2	1.2 ± 0.3	1.1 ± 0.1	1.0 ± 0.2
IRROM (°)	55.5 ± 9.5	56.2 ± 6.7	55.2 ± 6.9	51.2 ± 7.7
ERROM (°)	108.06 ± 12.3	105.7 ± 11.5	109.1 ± 9.1	103.5 ± 7.3
Posterior Shoulder Tightness (°)	18.9 ± 4.7	18.2 ± 4.9	24.3 ± 4.4	21.4 ± 4.9

REFERENCES

1. 2012 USA Swimming Membership Demographics. *USA Swimming.* 2012. http://www.usaswimming.org/_Rainbow/Documents/ceb07df5-c623-49a9-ad4c-dc331707b3a4/Statistics-2012.pdf.

2. Hibberd EE, Myers JB. Practice Habits and Attitudes and Behaviors Concerning Shoulder Pain in High School Competitive Club Swimmers. *Clinical Journal of Sport Medicine.* Nov 2013;23(6):450-455.

3. Weldon EJ, 3rd, Richardson AB. Upper extremity overuse injuries in swimming. A discussion of swimmer's shoulder. *Clin Sports Med.* Jul 2001;20(3):423-438.

4. McMaster WC. Shoulder injuries in competitive swimmers. *Clin Sports Med.* Apr 1999;18(2):349-359, vii.

5. Wolf BR, Ebinger AE, Lawler MP, Britton CL. Injury patterns in Division I collegiate swimming. *Am J Sports Med.* Oct 2009;37(10):2037-2042.

6. Beach ML, Whitney SL, Dickoff-Hoffman S. Relationship of shoulder flexibility, strength, and endurance to shoulder pain in competitive swimmers. *The Journal of orthopaedic and sports physical therapy.* 1992;16(6):262-268.

7. Pink MM, Tibone JE. The painful shoulder in the swimming athlete. *Orthop Clin North Am.* Apr 2000;31(2):247-261.

8. Sein ML, Walton J, Linklater J, et al. Shoulder pain in elite swimmers: primarily due to swim-volume-induced supraspinatus tendinopathy. *Br J Sports Med.* Feb 2010;44(2):105-113.

9. Bak K, Magnusson SP. Shoulder strength and range of motion in symptomatic and pain-free elite swimmers. *Am J Sports Med.* Jul-Aug 1997;25(4):454-459.

10. Richardson AR. The biomechanics of swimming: the shoulder and knee. *Clin Sports Med.* Jan 1986;5(1):103-113.

11. Kebaetse M, McClure P, Pratt NA. Thoracic position effect on shoulder range of motion, strength, and three-dimensional scapular kinematics. *Arch Phys Med Rehabil.* Aug 1999;80(8):945-950.

12. Wang CH, McClure P, Pratt NE, Nobilini R. Stretching and strengthening exercises: their effect on three-dimensional scapular kinematics. *Arch Phys Med Rehabil.* Aug 1999;80(8):923-929.

13. Finley MA, Lee RY. Effect of sitting posture on 3-dimensional scapular kinematics measured by skin-mounted electromagnetic tracking sensors. *Arch Phys Med Rehabil.* Apr 2003;84(4):563-568.

14. Kluemper M, Uhl TL, Hazelrigg H. Effect of Stretching and Strengthening Shoulder Muscles on Forward Shoulder Posture in Competitive Swimmers. *Journal of Sport Rehabilitation.* 2006;15(1):58.

15. Page P. Muscle imbalances in older adults:improving posture and decreasing pain. *The Journal on Active Aging.* 2005.

16. Borstad JD. Resting position variables at the shoulder: evidence to support a posture-impairment association. *Phys Ther.* Apr 2006;86(4):549-557.

17. Brossmann J, Preidler KW, Pedowitz RA, White LM, Trudell D, Resnick D. Shoulder impingement syndrome: influence of shoulder position on rotator cuff impingement--an anatomic study. *AJR Am J Roentgenol.* Dec 1996;167(6):1511-1515.

18. Solem-Bertoft E, Thuomas KA, Westerberg CE. The influence of scapular retraction and protraction on the width of the subacromial space. An MRI study. *Clin Orthop Relat Res.* Nov 1993(296):99-103.

19. Silva RT, Hartmann LG, Laurino CF, Bilo JP. Clinical and ultrasonographic correlation between scapular dyskinesia and subacromial space measurement among junior elite tennis players. *Br J Sports Med.* May 2010;44(6):407-410.

20. Kalra N, Seitz AL, Boardman ND, 3rd, Michener LA. Effect of posture on acromiohumeral distance with arm elevation in subjects with and without rotator cuff disease using ultrasonography. *J Orthop Sports Phys Ther.* Oct 2010;40(10):633-640.

21. Gumina S, Di Giorgio G, Postacchini F, Postacchini R. Subacromial space in adult patients with thoracic hyperkyphosis and in healthy volunteers. *La Chirurgia degli organi di movimento.* Feb 2008;91(2):93-96.

22. Cholewinski JJ, Kusz DJ, Wojciechowski P, Cielinski LS, Zoladz MP. Ultrasound measurement of rotator cuff thickness and acromio-humeral distance in the diagnosis of subacromial impingement syndrome of the shoulder. *Knee Surg Sports Traumatol Arthrosc.* Apr 2008;16(4):408-414.

23. Borstad JD, Ludewig P. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. *The journal of orthopaedic and sports physical therapy.* 2005;35(4):227-238.

24. Jansson A, Saartok T, Werner S, Renstrom P. Evaluation of general joint laxity, shoulder laxity and mobility in competitive swimmers during growth and in normal controls. *Scandinavian journal of medicine & science in sports.* Jun 2005;15(3):169-176.

25. Thomas SJ, Swanik CB, Higginson JS, et al. A bilateral comparison of posterior capsule thickness and its correlation with glenohumeral range of motion and scapular upward rotation in collegiate baseball players. *J Shoulder Elbow Surg.* Jul 2011;20(5):708-716.

26. Walker H, Gabbe B, Wajswelner H, Blanch P, Bennell K. Shoulder pain in swimmers: a 12-month prospective cohort study of incidence and risk factors. *Physical therapy in sport : official journal of the Association of Chartered Physiotherapists in Sports Medicine.* Nov 2012;13(4):243-249.

27. Harris C, Straker L. Survey of Physical Ergonomics Issues Associated with School Childrens' Use of Laptop Computers. *International Journal of Industrial Ergonomics.* 2000;26(3):337-346.

28. Devroey C, Jonkers I, de Becker A, Lenaerts G, Spaepen A. Evaluation of the effect of backpack load and position during standing and walking using biomechanical, physiological and subjective measures. *Ergonomics.* May 2007;50(5):728-742.

29. Asundi K, Odell D, Luce A, Dennerlein J. Notebook computer use on a desk, lap and lap support - effects on posture, performance and comfort. *Ergonomics.* 2010;53(1):74-82.

30. Thigpen C. Effects of forward head and rounded shoulder posture on scapular kinematics, muscle activity, and shoulder coordination. Chapel Hill: University of North Carolina at Chapel Hill; 2006.

31. Wang HK, Lin JJ, Pan SL, Wang TG. Sonographic evaluations in elite college baseball athletes. *Scandinavian journal of medicine & science in sports.* Feb 2005;15(1):29-35.

32. Michener LA, Subasi Yesilyaprak SS, Seitz AL, Timmons MK, Walsworth MK. Supraspinatus tendon and subacromial space parameters measured on ultrasonographic imaging in subacromial impingement syndrome. *Knee Surg Sports Traumatol Arthrosc.* Jun 5 2013.

33. Borstad JD. Measurement of pectoralis minor muscle length: validation and clinical application. *J Orthop Sports Phys Ther.* Apr 2008;38(4):169-174.

34. Norkin CC, White DJ. *Measurment of Joint Motion: A guide to Goniometry*. 2 ed. Philadelphia: F.A. Davis Company; 1995.

35. Myers JB, Oyama S, Wassinger CA, et al. Reliability, Precision, Accuracy, and Validity of Posterior Shoulder Tightness Assessment in Overhead Athletes. *The American journal of sports medicine.* Jul 3 2007.

36. Koskelo R, Vuorikari K, Hanninen O. Sitting and standing postures are corrected by adjustable furniture with lowered muscle tension in high-school students. *Ergonomics.* Oct 2007;50(10):1643-1656.

37. Chang Cea. Where and how college students use their laptop computers. Paper presented at: 52nd annual meeting of the human factors and ergonomics society2008.

38. Yeats B. Factors that may influence the postural health of schoolchildren (K-12). *Work.* 1997;9(1):45-55.

39. Asundi K, Odell D, Luce A, Dennerlein JT. Changes in posture through the use of simple inclines with notebook computers placed on a standard desk. *Applied ergonomics.* Mar 2012;43(2):400-407.

40. Peterson DE, Blankenship KR, Robb JB, et al. Investigation of the validity and reliability of four objective techniques for measuring forward shoulder posture. *J Orthop Sports Phys Ther.* Jan 1997;25(1):34-42.

41. Su KP, Johnson MP, Gracely EJ, Karduna AR. Scapular rotation in swimmers with and without impingement syndrome: practice effects. *Medicine and science in sports and exercise.* Jul 2004;36(7):1117-1123.

42. Harryman DT, 2nd, Sidles JA, Clark JM, McQuade KJ, Gibb TD, Matsen FA, 3rd. Translation of the humeral head on the glenoid with passive glenohumeral motion. *The Journal of bone and joint surgery. American volume.* Oct 1990;72(9):1334-1343.

43. Huffman GR, Tibone JE, McGarry MH, Phipps BM, Lee YS, Lee TQ. Path of glenohumeral articulation throughout the rotational range of motion in a thrower's shoulder model. *Am J Sports Med.* Oct 2006;34(10):1662-1669.

44. Clabbers KM, Kelly JD, Bader D, et al. Effect of posterior capsule tightness on glenohumeral translation in the late-cocking phase of pitching. *J Sport Rehabil.* Feb 2007;16(1):41-49.

45. Grossman MG, Tibone JE, McGarry MH, Schneider DJ, Veneziani S, Lee TQ. A cadaveric model of the throwing shoulder: a possible etiology of superior labrum anterior-to-posterior lesions. *The Journal of bone and joint surgery. American volume.* Apr 2005;87(4):824-831.

46. Laudner KG, Sipes RC, Wilson JT. The acute effects of sleeper stretches on shoulder range of motion. *J Athl Train.* Jul-Aug 2008;43(4):359-363.

47. Oyama S, Goerger CP, Goerger BM, Lephart SM, Myers JB. Effects of non-assisted posterior shoulder stretches on shoulder range of motion among collegiate baseball pitchers. *Ath Train Sport Health Care.* 2010;2(4):163-107.

48. Cools AM, Cambier D, Witvrouw EE. Screening the athlete's shoulder for impingement symptoms: a clinical reasoning algorithm for early detection of shoulder pathology. *British journal of sports medicine.* Aug 2008;42(8):628-635.

49. Tyler TF, Nicholas SJ, Lee SJ, Mullaney M, McHugh MP. Correction of posterior shoulder tightness is associated with symptom resolution in patients with internal impingement. *Am J Sports Med.* Jan 2010;38(1):114-119.

50. Jobe FW, Kvitne RS, Giangarra CE. Shoulder pain in the overhand or throwing athlete. The relationship of anterior instability and rotator cuff impingement. *Orthop Rev.* Sep 1989;18(9):963-975.

51. Virag B, Hibberd E, Oyama S, Padua D, Myers JB. Prevalence of Freestyle Biomechanical Errors in Elite Competitive Swimmers. *Sports health.* 2014;epub ahead of print.

52. Salo D, Riewald S. *Complete Conditioning for Swimming*. Champaign, IL: Human Kinetics; 2008.

53. Hibberd EE, Oyama S, Spang JT, Prentice W, Myers JB. Effect of a 6-week strengthening program on shoulder and scapular-stabilizer strength and scapular kinematics in division I collegiate swimmers. *J Sport Rehabil.* Aug 2012;21(3):253-265.

54. Ebaugh DD, McClure PW, Karduna AR. Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics. *J Electromyogr Kinesiol.* Jun 2006;16(3):224-235.

Manuscript 2

Effect of Swim Training on Physical Characteristics in Competitive Adolescent Swimmers

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Background: Interfering shoulder pain is reported in 45-87% of swimmers at some time during their careers. Subacromial space distance, forward head and shoulder posture, and pectoralis minor length are characteristics that have been theorized to change due to anterior shoulder musculature tightness and posterior shoulder muscle weakness as a result of swim training. These alterations can cause abnormal scapular kinematics and positioning, potentially increasing compression of structures in the subacromial space and increasing the risk for the development of swimmer's shoulder.

Purpose: The purpose of this research study was to evaluate the effect of the swim training season on subacromial space distance, forward head and forward shoulder posture, and pectoralis minor length, as well as determine the relationship between these variables.

Study Design: Cohort Repeated-Measures Design

Methods: 45 competitive adolescent swimmers and 31 non-overhead adolescent athletes (controls) that were not currently experiencing any shoulder, neck, or back pain that limited their participation in sports activity were included in the study. All participants were evaluated 3 times: once prior to the start of the swimming training season and then at 2 follow-up sessions 6 and 12 weeks following the initial testing session. At each testing session, each participant completed a physical exam that included evaluation of posture, subacromial space distance, and pectoralis minor muscle length.

Results: Swimmers presented with significantly greater decreases in subacromial space distance during the training season compared to non-overhead athletes. Swimmers also demonstrated significantly greater increases in forward shoulder posture compared to non-overhead athletes. There was a significant relationship between changes in forward shoulder posture and changes in subacromial space distance from the baseline testing session to the assessment 6-weeks following baseline assessment. As forward shoulder posture increased subacromial space significantly decreased.

Conclusions: Due to the training load, swimmers experience a decrease in subacromial space distance and increase in forward shoulder posture, potentially making the athlete more vulnerable to the development of shoulder pain and injury.

Clinical Relevance: These findings indicate the importance of implementing an injury prevention program in competitive swimmers that strengthens the posterior scapular stabilizing musculature and stretches the anterior musculature to improve scapular functioning and control to potentially decrease shoulder pain and injury in competitive swimmers.

Key Terms: Swimming, Subacromial Space Distance, Forward Shoulder Posture, Forward Head Posture

Word Count: 348/350

Introduction

Competitive club swimming is a year round sport with very limited time for rest and recovery.[1,2] The competitive swimming season is broken into a cardiovascular/endurance phase that occurs in the training season and a taper period that occurs in the competition season.[3] During the training season, competitive swimmers perform a large volume of yardage with high intensity practices in order to gain strength and power.[4] As the competition season approaches, swimmers begin to taper, which allows for muscle recovery and rest, ultimately optimizing physiological and psychological components to maximize performance in competitions.[5,6] Typically, swimmers train and taper for two major meets during the year, taking a few weeks off between their competition and the time when they start their training again.

Competitive youth swimmers train 11 months out of the year and perform approximately 6,000-7,000 yards per practice during the training season[1] with little rest and time for muscle recovery from repetitive microtrauma.[7] Due to these high levels of training, it is hypothesized that physical characteristics of swimmers' upper extremities adapt to the demands that are placed on them and predispose them to "swimmer's shoulder," which is the general term for overuse injury in swimming athletes.[2,8,9] "Swimmer's shoulder" is commonplace in swimming, as at least 55% of all injuries in competitive swimmers affect the shoulder.[10] Further, interfering shoulder pain has been reported in 45-87% of swimmers during their careers.[7,11,12] In competitive youth swimmers, 85% of swimmers believe that mild shoulder pain is normal and should be tolerated in order to complete the necessary yardage, with

72% of the swimmers reporting use of pain medication (either prescribed or over-the-counter) in order to participate.[1] The prevalence of shoulder injuries and the beliefs regarding shoulder pain in youth swimmers highlight the need for an effective assessment tool and intervention program to be validated.

Clinically, athletic trainers treat a high percentage of athletes reporting for management of shoulder pain during the training season. Due to the high training load, it is hypothesized that physical characteristics of swimmers change due to participation factors and predispose the athlete to shoulder pain and injury.[2] While the exact cause of “swimmer’s shoulder” and the associated pain is unknown, several theories have been hypothesized including decreased subacromial space distance, scapular dysfunction, altered muscle recruitment patterns, posterior shoulder tightness, humeral head displacement and altered physical characteristics.[13-24] Identifying adaptations of physical characteristics and risk factors of “swimmer’s shoulder” is imperative in order to understand how participation affects the potential risk factors and to accomplish our ultimate goal of preventing shoulder injuries in competitive swimmers.

Subacromial space distance, forward head posture, forward shoulder posture, and pectoralis minor length are characteristics that have been theorized to change due to anterior shoulder musculature tightness and posterior shoulder muscle weakness, which causes abnormal scapular kinematics and positioning.[25] Muscle length changes that occur in swimming are due to the repetitive nature of the sport and the fact that the majority of training is performed using the freestyle stroke where the swimmer is prone in the water using the anterior musculature, including the pectoral muscles, the serratus anterior and the upper trapezius to generate power in the water.[26]

Narrowing of the subacromial space width has been partially attributed to abnormal glenohumeral and scapular kinematics, [27-30] which have also previously been related to forward shoulder posture[31-34] and a shortened pectoralis minor length.[35] A decrease in the subacromial space distance increases the mechanical compression on the contents of the subacromial space and is an intrinsic risk factor for the development of impingement and swimmers shoulder. A decrease in subacromial space, identified using diagnostic ultrasound, has been found on the affected shoulder of individuals with impingement syndrome when compared to asymptomatic controls.[36] Faulty postural alignment and poor posture over time can lead to abnormal stress on tissues that may contribute to shoulder pain.[25] Muscle imbalances may alter biomechanics, as well as contribute to secondary impingement, joint instability and fatigue.

These alterations are hypothesized to develop due to training load, but research is needed to determine the effect of swim training on these physical characteristics that may pathological. Therefore, the purpose of this research study was to prospectively identify the effect of the training season on subacromial space distance, forward head posture, forward shoulder posture, pectoralis minor length as well as determine the relationship between these variables. Evaluating these changes in the physical characteristics in competitive swimmers may advance our understanding of the effects of swim training on physical characteristics and provide support for future studies focusing on injury prevention programs.

Methods

A cohort repeated measures research design with a group of competitive adolescent swimmers and a non-overhead athlete control group were utilized in the current study. All participants in the study participated in three data collections: baseline (prior to the start of the swimming training season), 6 weeks post baseline assessment (mid-training season), and 12 weeks post baseline assessment (end of training season). At each testing session, data collection occurred prior to the start of a team practice and participants filled out a demographics questionnaire and completed a physical exam that included measures of posture, subacromial space distance, and pectoralis minor length.

Participants

Participants were recruited for both a swimming group and non-overhead athlete control group. Participants were both males and females between the ages of 13 and 18 years old. Swimming participants were included in the research study if they met all of the following criteria: member of a senior (top training level) team on their club team, regularly train at least 4 times per week, 1-2 hours each practice session and not currently experiencing back, neck or shoulder pain that limits their ability to participate. Swimming participants were excluded from the research study if they met the following criteria: had less than 2 years of competitive swimming experience, had limitations in practice or were unable to complete practices fully due to pain, injury, or illness for more than 2 weeks during the training season, used any type of external, correctional posture device, or had a history of shoulder surgery.

Non-overhead athletes were included to account for changes in physical characteristics that occur due to maturation. Non-overhead athletes were recruited from local soccer and track and cross-country leagues and were included in this research study if they: had not participated on an organized team of an overhead dominant sport for more than 1 year (e.g. baseball, softball, tennis, volleyball, swimming) and were not experiencing back, neck, or shoulder pain that limited participation during the course of the study. Non-overhead athletes were excluded from this research study if they: had a history of shoulder surgery, were experiencing any shoulder pain that limited participation at the time of testing, were using any type of external, correctional posture device, were performing rehabilitation (strengthening and stretching) that targets upper extremity physical characteristics, or developed back, neck or shoulder pain that limited their ability to participate in activity for more than 2 weeks.

Procedures

Prior to data collection, the primary investigator met with all potential participants and distributed information packets regarding the research study. Those interested in participating and their parents/guardians read and signed the informed consent form approved by a University Institutional Review Board. Participants completed a demographics form and had their physical characteristics assessed at three time points during the swimming training season- prior to the training season, 6 weeks following the initial testing session, and following the training season (12 weeks after the initial training session). At each session, participants completed a demographics form that included questions about years of swim experience, event specialization, practice requirements and previous injury history. All forms were collected at the beginning of the testing session. Participants completed their typical warm-up and then rotated through the testing stations.

Subacromial space distance was measured using a portable diagnostic ultrasound machine (LOGIQe, General Electric, Milwaukee, Wisconsin, USA) using procedures previously defined by Wang et al.[37] Each participant was assessed seated in a chair with their forearm resting on his/her thigh in pronation **(Figure 1A)**. Sound coupling gel was applied to the ultrasound transducer, which was then placed in the coronal plane of the shoulder. When the lateral acromion and humeral head could clearly be visualized, the image was saved for later analysis. Three trials were performed bilaterally. After measurements had been taken at all of the 3 time points, a research assistant re-labeled the stored images, so that the primary investigator who evaluated the subacromial space distance was blinded to testing session to prevent any bias from entering the assessment. The primary investigator then measured subacromial space width using Image J software (National Institute of Health, Bethesda, MD). Subacromial space distance was defined as the shortest distance between the anterior-inferior tip of the acromion and the humeral head **(Figure 1B)**.[38] The average of the 3 trials was taken for each side. Prior to data collection, strong reliability and precision were demonstrated for measuring subacromial space distance (ICC= 0.91, SEM=0.04 cm).

Reflective markers were placed on the dominant side of each participant on the following anatomical landmarks: tragus, C7, and anterior tip of the acromion.[39] While standing in front of a horizontal reference line, participants performed 3 overhead squats and were then instructed to stand in “a relaxed position” while a picture was taken in the sagittal plane. Following the initial photograph, participants were then instructed to complete three additional overhead squats. Following the series of three squats, the participants were instructed to “relax” and “stand in normal position” while photographs were repeated in the sagittal plane. Participants performed one additional set of three squats, “relaxing” and “standing in normal posture” for subsequent photographs to be taken.

The landmarks were digitized to calculate the forward head angle (defined as the angle of inclination between the line extending from C7 to tragus and the vertical line) **(Figure 2A)** and the forward shoulder angle (defined as the angle of inclination between the line extending from C7 to the shoulder and the vertical line) **(Figure 2B)** for each participant. The dependent variables assessed were forward head angle and forward shoulder angle. A three-trial mean was calculated for each posture variable. Prior to data collection, strong intrasession reliability and precision were demonstrated for forward head posture (ICC= 0.98 SEM=0.73°) and forward shoulder posture (ICC= 0.99 SEM=0.88°)

Pectoralis minor length was measured with the participant lying supine on the table.[40] Pectoralis minor muscle length were measured using vernier calipers (Westward Tools, Edmonton, AB, Canada) to measure the distance between the medial-inferior aspect of the coracoid process to the anterior-inferior edge of the 4th rib just lateral to sternocostal junction **(Figure 3)**. A three-trial mean was calculated for pectoralis minor length. Prior to data collection, strong intrasession reliability and precision were demonstrated for pectoralis minor length (ICC= 0.92, SEM=0.42 cm).

This method of measurement of the pectoralis minor muscle length has also been validated using cadavers.[41]

Statistical Analyses

Percent change scores were calculated as the difference between testing session 2 and baseline and testing session 3 and baseline. Statistical analyses were run using SPSS version 20.0 software (company info). A 2 way mixed model ANOVA (time-by-group) was used to analyze the percent change of forward head and forward posture variables. A 3-way mixed model ANOVA (limb X time-by-group) was used to analyze the percent change of subacromial space distance and pectoralis minor length. Pearson product-moment correlations were also used to evaluate the relationship between forward shoulder posture, subacromial space distance and pectoralis minor length. An a priori alpha level of 0.05 was set for all comparisons for statistical significance.

Results

Seventy-five participants were screened for participation in the research study (44 competitive swimmers and 31 non-overhead athletes). Over the 12-week training season, there was a 97% retention rate for swimmers. One swimmer withdrew from the study due to shoulder pain, which resulted in surgery. There was a 94% retention rate for non-overhead athletes. Two control participants withdrew: one due to illness that lasted for longer than 2 weeks that caused missed participation and one due to illness on the days of the second testing session. Therefore, there were a total of 72 participants included in the analysis of changes that occurred over the course of the training season. Participant demographics are included in **Table 1.** Mean change scores for each variable are presented in **Table 2.**

There was a significant main effect for group for forward shoulder posture ($F_{1, 70}$=19.84, *p*<0.001). Swimmers demonstrated significantly greater changes in forward shoulder posture compared to non-overhead athletes **(Figure 4)**. There was no significant main effect of time (*p*=0.38) and no significant group by time interaction (*p*=0.24) for forward shoulder posture. Swimmers forward shoulder posture increased by approximately 15% over the course of the training season, while non-overhead athletes only increased by approximately 1%. There was a significant main effect of time for forward head posture ($F_{1, 70}$=13.2, *p*=0.001). All participants moved into significantly more forward head posture over the course of the study **(Figure 5).** There was no significant main effect of group (*p*=0.98) or group by time interaction for forward head posture (*p*=0.31).

There was a significant group-by-time interaction in percent change scores for subacromial space distance ($F_{1, 70}$=9.827, *p*=0.003) **(Figure 6)**. There was a significant main effect for group, as swimmers had significantly greater decreases in subacromial space distance than non-overhead athletes over the course of the training season ($F_{1, 70}$=26.025, *p*<0.001), but no main effect for time (*p*=0.50). Over the course of the training season, swimmers subacromial space distance decreased by 8.5%, while non-overhead athlete's subacromial space distance slightly increased by 2.5%. There was not a significant limb-by-time-by group (*p*=0.65) or limb-by-time (*p*=0.68) interaction and no main effect of time (0.30) or limb (0.18) for changes in subacromial space distance over the training season.

There was a significant group-by-time ($F_{1, 70}$=5.703, p=0.02) and group-by-limb interaction for change scores of pectoralis minor length, but no significant main effect of time (p=0.89), limb (p=0.31), or group (p=0.12). The limb-by-time-by-group interaction was not significant (p=0.90).

There was a significant fair–to-moderate negative relationship between changes in forward shoulder posture and changes in dominant normalized subacromial space distance (r_{68}=-0.49, p<0.001) between baseline and the 6-week follow up test sessions. A similar relationship was found between changes in forward shoulder posture and changes in non-dominant normalized subacromial space distance (r_{68}=-0.47, p<0.001) over the 6 week period. Correlations between changes in pectoralis minor muscle length and forward shoulder posture and subacromial space distance were not significant.

Discussion

There was a significantly less subacromial space in both the dominant and non-dominant limbs of the swimmers over the course of the training season when compared to the non-overhead athletes. It is hypothesized that the decreased subacromial space in individuals with impingement syndrome can be due to lost scapular control manifesting as altered scapular kinematic patterns.[42] Tennis players with scapular dyskinesia have been found to have significantly smaller subacromial space distance than individuals who do not have scapular dyskinesia.[42] It has previously been reported that swimmers' scapulae became more internally rotated, protracted and elevated over the first 6-weeks of the training season in collegiate swimmers. [43] This high level of training during the first-6 weeks of the training season may cause muscle fatigue, muscle imbalance, or tightness to develop in the shoulder musculature altering scapular kinematics. This pattern of scapular kinematics may put the swimmer at an increased risk for shoulder impingement because of increased contact of the acromion and rotator cuff tendons from decreased subacromial space.[19,44,45] These alterations in scapular kinematics may also be present in the participants of the current study and be the cause of the significant decrease in subacromial space that is observed in competitive swimmers during the training season.

The swimmers in the current study also presented with significantly greater increases in forward shoulder posture compared to the non-overhead athletes over the 6-week testing period. Forward shoulder posture along with an increase in thoracic kyphosis can be indicated by tight pectoral muscles coupled with weakness of the middle and lower trapezius.[25] However, the current study did not find a significant decrease in pectoralis minor length in the competitive swimmers over the training season compared to the control group. Due to contribution of the pectoralis major in propulsion of the body during the swimming strokes, increases in muscle tension (thus associated decreases in muscle length) of the pectoralis major may be more likely to develop due to swim training.[46,47] The constant use of the pectoralis major may cause adaptive shortening of the muscle in swimmers, ultimately causing the shoulder girdle to be positioned more anteriorly.[26] The anterior pull on the shoulder girdle by the anterior musculature puts the posterior muscles, involved in pulling the scapulae back towards the spine, on a constant stretch that eventually causes them to lengthen and weaken which contributes to forward shoulder posture.[26]

In a study by Kebaetse et al [31] individuals in a slouched posture had significantly less upward rotation and posterior tipping, as well as increased internal rotation of the scapula between 90° and maximum shoulder abduction occurred when compared to an upright posture. This study also found a 16.2% decrease in the glenohumeral muscle strength and ability to generate muscle force in the slouched posture.[31] The alterations in scapular kinematics and decreased muscle strength associated with a slouched, forward shoulder posture have been theorized to decrease the subacromial space distance, thus increasing the risk of impingement.[13,42,48,49] This theory is supported by the findings of this research study, as a significant negative correlation was present between changes in forward shoulder posture and changes in subacromial space distance, indicating that as forward shoulder posture increase, subacromial space distance significantly decreased. Increases in forward shoulder posture with the associated decreases in the width of the subacromial space may increase mechanical compression on the soft tissue structures of this space thereby increasing the risk of developing shoulder pain and injury.[50,51]

Both decreases in the size of the subacromial space and excessive forward shoulder posture have been associated with mechanical compression of the soft tissue contents located in the subacromial space and subsequently as an intrinsic risk factor for the development of impingement.[31-34,42] Based on these previous findings and the results of the current study, which show that swimmers develop these pathological characteristics while training, such athletes may benefit from an intervention strengthening and stretching program. This type of program could be implemented prior to and during the training season with the aim of improving scapular stabilization in an effort to prevent decreases in subacromial space distance, increases in forward shoulder posture, and ultimately shoulder pain and injury. Previous literature has found a strong, direct correlation between increases in the subacromial space distance and functional outcomes as measured by the Western Ontario Rotator Cuff Index among impingement patients.-(ref) These findings indicated that improvements in subacromial space width both decrease the chance of injury and also improve the functioning of the athlete.[52]

In a study by Kluemper et al [34] a 6-week conditioning program emphasizing strengthening for scapular retraction, shoulder external rotation, and shoulder flexion, as well as stretching the pectoralis minor and major significantly decreased forward shoulder posture. Similarly, Wang et al [32] implemented a 6 week strengthening and stretching program on asymptomatic participants with forward shoulder posture. The program consisted of strengthening for scapular retraction, shoulder shrugging, shoulder abduction, and shoulder external rotation, as well as corner stretching exercises. After the intervention, a significant increase in isometric strength for external rotation, internal rotation and horizontal abduction occurred. However, no significant difference was found in three-dimensional scapular position at rest after the 6 weeks, although change in scapulohumeral rhythm was found, when the arm was actively elevated to 90°. The scapula was found to be less upwardly rotated, superiorly translated and more internally rotated. These authors concluded that following the exercise program the scapular muscles were better able to stabilize the scapula on the thorax thereby decreasing the risk of injury. Based on the increases in forward shoulder found in the swimmers of the current study, these intervention programs may be useful in the prevention of injury among competitive swimmers.

In the current study, the changes that were observed occurred over the swim training season, as a result of the swimmers training demands. Due to the current popular theory of swim training, swimmers train at high volumes with a large number of yards being performed per practice with many practices a week.[53] This training load may not allow competitive swimmers adequate time to rest and recover between practices, resulting in the alterations in physical characteristics observed in the current study. Unlike baseball pitching, there are no participation guidelines or indicators of rest following these extreme loads of swim training. Future research should identify physiological adaptations that occur due to training and how these adaptations relate to performance factors and physical characteristics. This research would aid in the development of evidence-based participation guidelines that would maximize performance while decreasing injury risk. In addition, future research should work to identify additional physical characteristics change over the course of the training season, such as scapular kinematics and muscle strength to help develop targeted interventions. Finally, future research should identify specifically when the adaptations occur during the training season, which would help to identify the most appropriate time to implement an evidence-based intervention program to maximize the benefits and decrease injury risk.

Conclusion

Due to the training load, swimmers experience a significant decrease in subacromial space distance and significant increase in forward shoulder posture, potentially making the athlete more vulnerable to the development of shoulder pain and injury. Over the course of the training season, swimmers develop risk factors that may be causative of impingement and the development of swimmer's shoulder. These findings indicate the importance of implementing an injury prevention program in competitive swimmers that strengthens the posterior scapular stabilizing musculature and stretches the anterior musculature. Improvements in these areas would improve scapular functioning and control, thus improving subacromial space distance and forward shoulder posture and ultimately decreasing shoulder pain and injury in competitive swimmers. The findings of this study also highlight the importance of understanding the role of participation factors in contributing to changes in physical characteristics and future studies that focus on maximizing performance while minimizing injury risk.

Figure Legend:

Figure 1: Posture Assessment- (A) Forward Head Angle (B) Forward Shoulder Angle

Figure 2: Measurement of Subacromial Space Distance- (A) Subject positioning (B) Ultrasound measurement of subacromial space distance

Figure 3: Pectoralis Minor Length Measurement

Figure 4: Forward Shoulder Posture Changes

Figure 5: Forward Head Posture Changes

Figure 6: Subacromial Space Distance Changes

Figure 1: Posture Assessment- (A) Forward Head Angle (B) Forward Shoulder Angle

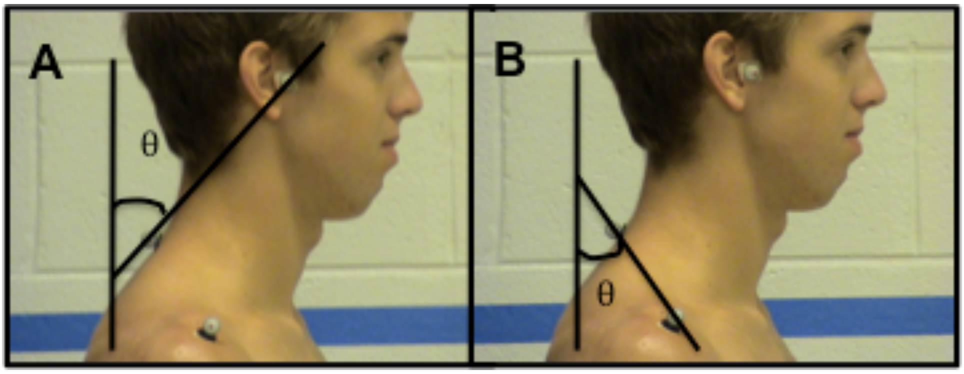

Figure 2: Measurement of Subacromial Space Distance- (A) Subject positioning (B) Ultrasound measurement of subacromial space distance

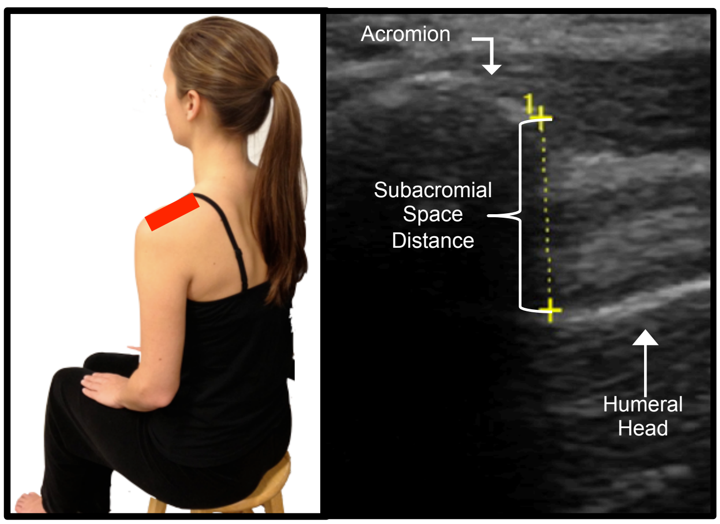

Figure 3: Pectoralis Minor Length Measurement

Figure 4: Forward Shoulder Posture Changes

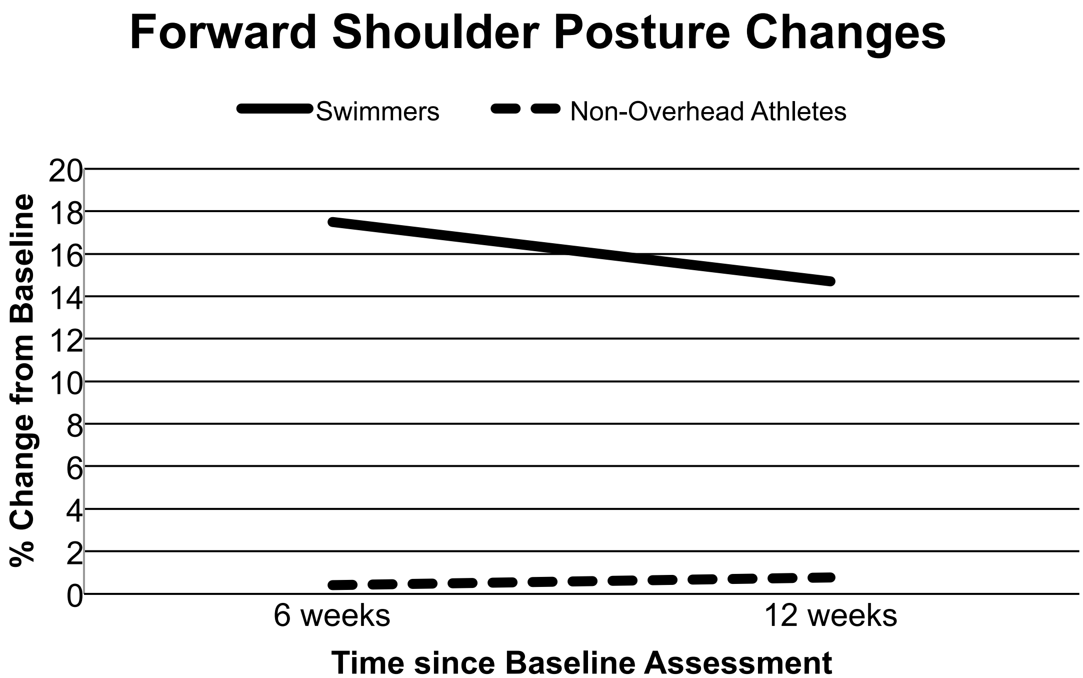

Figure 5: Forward Head Posture Changes

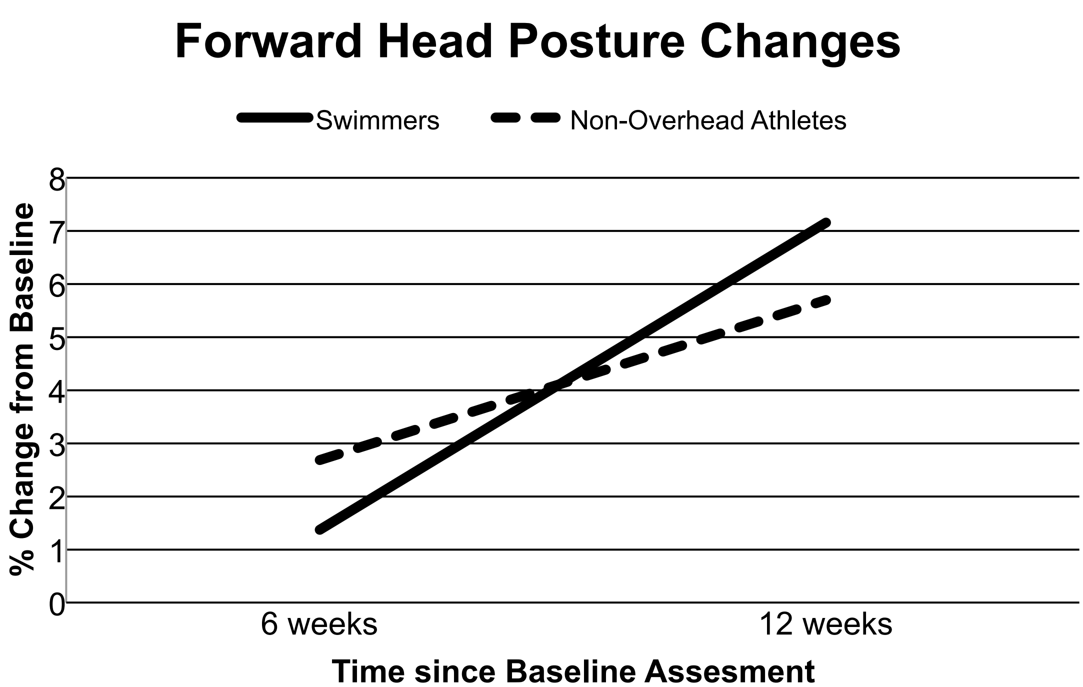

Figure 6: Subacromial Space Distance Changes

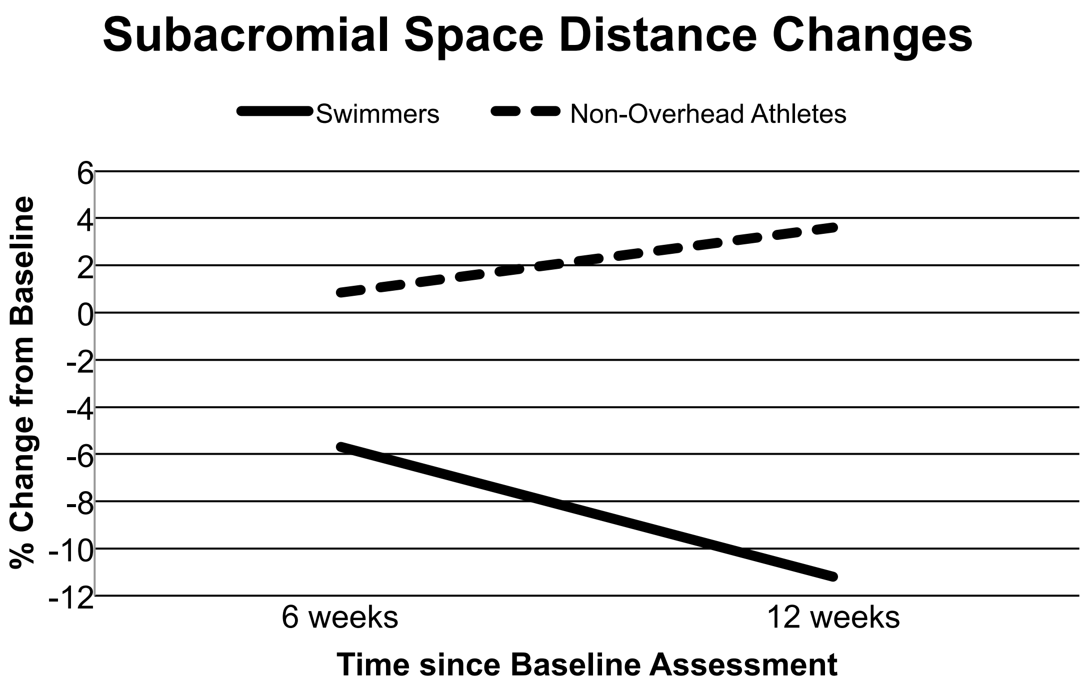

Table 1: Participant Demographics

	Swimmers	Non-overhead Athletes
n	43 (25F; 18M)	29 (19F; 10M)
Age (yrs)	16.5 ± 1.0	16.5 ± 1.1
Height (cm)	172.3 ± 13.0	169.3 ± 8.2
Mass (kg)	66.2 ± 10.3	57.9 ± 8.4

Table 2: Mean Change Scores

	Swimmers		Non-overhead athletes	
	% Change Pre-6 weeks	*% Change Pre-12 weeks*	*% Change Pre-6 weeks*	*% Change Pre-12 weeks*
Forward Shoulder Posture	17.5 ± 17.6	14.9 ± 19.3	0.4 ± 8.6	0.8 ± 11.8
Forward Head Posture	1.4 ± 11.1	7.2 ± 13.7	2.7 ± 9.6	6.0 ± 8.3
Dominant Subacromial Space Distance	-5.9 ± 6.0	-10.7 ± 11.7	-1.2 ± 0.9	1.5± 13.0
Non-Dominant Subacromial Space Distance	-5.5 ± 11.6	-11.7 ± 14.8	2.9 ± 0.9	5.7 ± 17.0
Dominant Pectoralis Minor Length	2.6 ± 9.0	0.7 ± 8.8	-2.7 ± 13.5	-0.5 ± 10.3
Non-Dominant Pectoralis Minor Length	3.7 ± 8.2	1.79 ± 8.1	-4.6 ± 11.8	-2.4 ± 9.5

REFERENCES

1. Hibberd EE, Myers JB. Practice Habits and Attitudes and Behaviors Concerning Shoulder Pain in High School Competitive Club Swimmers. *Clinical Journal of Sport Medicine.* Nov 2013;23(6):450-455.

2. Sein ML, Walton J, Linklater J, et al. Shoulder Pain in Elite Swimmers: Primarily Due to Swim-Volume-Induced Supraspinatus Tendinopathy. *British journal of sports medicine.* Feb 2010;44(2):105-113.

3. Hannula D, Thornton N, eds. *The Swim Coaching Bible*. Champaign: Human Kinetics; 2001.

4. Salo D, Riewald S. *Complete Conditioning for Swimming*. Champaign, IL: Human Kinetics; 2008.

5. Mujika I, Padilla S. Detraining: Loss of Training-Induced Physiological and Performance Adaptations. Part Ii: Long Term Insufficient Training Stimulus. *Sports medicine.* Sep 2000;30(3):145-154.

6. Mujika I, Padilla S. Scientific Bases for Precompetition Tapering Strategies. *Medicine and science in sports and exercise.* Jul 2003;35(7):1182-1187.

7. Beach ML, Whitney SL, Dickoff-Hoffman S. Relationship of Shoulder Flexibility, Strength, and Endurance to Shoulder Pain in Competitive Swimmers. *J Orthop Sports Phys Ther.* 1992;16(6):262-268.

8. Bak K, Magnusson SP. Shoulder Strength and Range of Motion in Symptomatic and Pain-Free Elite Swimmers. *Am J Sports Med.* Jul-Aug 1997;25(4):454-459.

9. Richardson AR. The Biomechanics of Swimming: The Shoulder and Knee. *Clin Sports Med.* Jan 1986;5(1):103-113.

10. McFarland EG, Wasik M. Injuries in Female Collegiate Swimmers Due to Swimming and Cross Training. *Clin J Sport Med.* Jul 1996;6(3):178-182.

11. Johnson D. In Swimming, Shoulder the Burden. *Sportcare Fitness.* 1988;May-June:24-30.

12. Pink MM, Tibone JE. The Painful Shoulder in the Swimming Athlete. *Orthop Clin North Am.* Apr 2000;31(2):247-261.

13. Solem-Bertoft E, Thuomas KA, Westerberg CE. The Influence of Scapular Retraction and Protraction on the Width of the Subacromial Space. An Mri Study. *Clin Orthop Relat Res.* Nov 1993(296):99-103.

14. Deutsch A, Altchek DW, Schwartz E, et al. Radiologic Measurement of Superior Displacement of the Humeral Head in the Impingement Syndrome. *J Shoulder Elbow Surg.* May-Jun 1996;5(3):186-193.

15. Ludewig PM, Cook TM, Nawoczenski DA. Three-Dimensional Scapular Orientation and Muscle Activity at Selected Positions of Humeral Elevation. *J Orthop Sports Phys Ther.* Aug 1996;24(2):57-65.

16. Wadsworth DJ, Bullock-Saxton JE. Recruitment Patterns of the Scapular Rotator Muscles in Freestyle Swimmers with Subacromial Impingement. *Int J Sports Med.* Nov 1997;18(8):618-624.

17. Graichen H, Bonel H, Stammberger T, et al. Three-Dimensional Analysis of the Width of the Subacromial Space in Healthy Subjects and Patients with Impingement Syndrome. *AJR Am J Roentgenol.* Apr 1999;172(4):1081-1086.

18. Lukasiewicz AC, McClure P, Michener L, et al. Comparison of 3-Dimensional Scapular Position and Orientation between Subjects with and without Shoulder Impingement. *J Orthop Sports Phys Ther.* Oct 1999;29(10):574-583; discussion 584-576.

19. Ludewig PM, Cook TM. Alterations in Shoulder Kinematics and Associated Muscle Activity in People with Symptoms of Shoulder Impingement. *Phys Ther.* Mar 2000;80(3):276-291.

20. Tyler TF, Nicholas SJ, Roy T, et al. Quantification of Posterior Capsule Tightness and Motion Loss in Patients with Shoulder Impingement. *Am J Sports Med.* Sep-Oct 2000;28(5):668-673.

21. Tsai NT, McClure PW, Karduna AR. Effects of Muscle Fatigue on 3-Dimensional Scapular Kinematics. *Arch Phys Med Rehabil.* Jul 2003;84(7):1000-1005.

22. Karduna AR, Kerner PJ, Lazarus MD. Contact Forces in the Subacromial Space: Effects of Scapular Orientation. *J Shoulder Elbow Surg.* Jul-Aug 2005;14(4):393-399.

23. Myers JB, Laudner KG, Pasquale MR, et al. Glenohumeral Range of Motion Deficits and Posterior Shoulder Tightness in Throwers with Pathologic Internal Impingement. *Am J Sports Med.* Mar 2006;34(3):385-391.

24. Santos MJ, Belangero WD, Almeida GL. The Effect of Joint Instability on Latency and Recruitment Order of the Shoulder Muscles. *J Electromyogr Kinesiol.* Apr 2007;17(2):167-175.

25. Page P. Muscle Imbalances in Older Adults:Improving Posture and Decreasing Pain. *The Journal on Active Aging.* 2005.

26. Peterson DE, Blankenship KR, Robb JB, et al. Investigation of the Validity and Reliability of Four Objective Techniques for Measuring Forward Shoulder Posture. *J Orthop Sports Phys Ther.* Jan 1997;25(1):34-42.

27. Ludewig P, Cook T. Alterations in Shoulder Kinematics and Associated Muscle Activity in People with Symptoms of Shoulder Impingement. *Physical therapy.* 2000;80(3):276-291.

28. Borich MR, Bright J, Lorello D, et al. Scapular Angular Positioning at End Range Internal Rotation in Cases of Glenohumeral Internal Rotation Deficit. *The journal of orthopaedic and sports physical therapy.* 2006;36(12):926-934.

29. Hébert LJ, Moffet H, McFadyen B, et al. Scapular Behavior in Shoulder Impingement Syndrome. *Archives of physical medicine and rehabilitation.* 2002;83(1):60-69.

30. Maenhout A, Van Eessel V, Van Dyck L, et al. Quantifying Acromiohumeral Distance in Overhead Athletes with Glenohumeral Internal Rotation Loss and the Influence of a Stretching Program. *The American journal of sports medicine.* 2012;40(9):2105-2112.

31. Kebaetse M, McClure P, Pratt NA. Thoracic Position Effect on Shoulder Range of Motion, Strength, and Three-Dimensional Scapular Kinematics. *Arch Phys Med Rehabil.* Aug 1999;80(8):945-950.

32. Wang CH, McClure P, Pratt NE, et al. Stretching and Strengthening Exercises: Their Effect on Three-Dimensional Scapular Kinematics. *Arch Phys Med Rehabil.* Aug 1999;80(8):923-929.

33. Finley MA, Lee RY. Effect of Sitting Posture on 3-Dimensional Scapular Kinematics Measured by Skin-Mounted Electromagnetic Tracking Sensors. *Arch Phys Med Rehabil.* Apr 2003;84(4):563-568.

34. Kluemper M, Uhl TL, Hazelrigg H. Effect of Stretching and Strengthening Shoulder Muscles on Forward Shoulder Posture in Competitive Swimmers. *Journal of Sport Rehabilitation.* 2006;15(1):58.

35. Borstad JD, Ludewig P. The Effect of Long Versus Short Pectoralis Minor Resting Length on Scapular Kinematics in Healthy Individuals. *J Orthop Sports Phys Ther.* 2005;35(4):227-238.

36. Cholewinski JJ, Kusz DJ, Wojciechowski P, et al. Ultrasound Measurement of Rotator Cuff Thickness and Acromio-Humeral Distance in the Diagnosis of Subacromial Impingement Syndrome of the Shoulder. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA.* Apr 2008;16(4):408-414.

37. Wang HK, Lin JJ, Pan SL, et al. Sonographic Evaluations in Elite College Baseball Athletes. *Scand J Med Sci Sports.* Feb 2005;15(1):29-35.

38. Michener LA, Subasi Yesilyaprak SS, Seitz AL, et al. Supraspinatus Tendon and Subacromial Space Parameters Measured on Ultrasonographic Imaging in Subacromial Impingement Syndrome. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA.* Jun 5 2013.

39. Thigpen C. Effects of Forward Head and Rounded Shoulder Posture on Scapular Kinematics, Muscle Activity, and Shoulder Coordination. Chapel Hill: University of North Carolina at Chapel Hill; 2006.

40. Lewis JS, Valentine RE. The Pectoralis Minor Length Test: A Study of the Intra-Rater Reliability and Diagnostic Accuracy in Subjects with and without Shoulder Symptoms. *BMC Musculoskelet Disord.* 2007;8:64.

41. Borstad JD. Measurement of Pectoralis Minor Muscle Length: Validation and Clinical Application. *J Orthop Sports Phys Ther.* Apr 2008;38(4):169-174.

42. Silva RT, Hartmann LG, Laurino CF, et al. Clinical and Ultrasonographic Correlation between Scapular Dyskinesia and Subacromial Space Measurement among Junior Elite Tennis Players. *British journal of sports medicine.* May 2010;44(6):407-410.

43. Hibberd EE, Oyama S, Spang JT, et al. Effect of a 6-Week Strengthening Program on Shoulder and Scapular-Stabilizer Strength and Scapular Kinematics in Division I Collegiate Swimmers. *J Sport Rehabil.* Aug 2012;21(3):253-265.

44. Ludewig PM, Reynolds JE. The Association of Scapular Kinematics and Glenohumeral Joint Pathologies. *J Orthop Sports Phys Ther.* Feb 2009;39(2):90-104.

45. Michener LA, McClure PW, Karduna AR. Anatomical and Biomechanical Mechanisms of Subacromial Impingement Syndrome. *Clin Biomech (Bristol, Avon).* Jun 2003;18(5):369-379.

46. Pink M, Perry J, Browne A, et al. The Normal Shoulder During Freestyle Swimming. An Electromyographic and Cinematographic Analysis of Twelve Muscles. *Am J Sports Med.* Nov-Dec 1991;19(6):569-576.

47. Pink M, Jobe FW, Perry J, et al. The Normal Shoulder During the Butterfly Swim Stroke. An Electromyographic and Cinematographic Analysis of Twelve Muscles. *Clin Orthop Relat Res.* Mar 1993(288):48-59.

48. Borstad JD. Resting Position Variables at the Shoulder: Evidence to Support a Posture-Impairment Association. *Phys Ther.* Apr 2006;86(4):549-557.

49. Brossmann J, Preidler KW, Pedowitz RA, et al. Shoulder Impingement Syndrome: Influence of Shoulder Position on Rotator Cuff Impingement--an Anatomic Study. *AJR Am J Roentgenol.* Dec 1996;167(6):1511-1515.

50. Kalra N, Seitz AL, Boardman ND, 3rd, et al. Effect of Posture on Acromiohumeral Distance with Arm Elevation in Subjects with and without Rotator Cuff Disease Using Ultrasonography. *J Orthop Sports Phys Ther.* Oct 2010;40(10):633-640.

51. Gumina S, Di Giorgio G, Postacchini F, et al. Subacromial Space in Adult Patients with Thoracic Hyperkyphosis and in Healthy Volunteers. *Chir Organi Mov.* Feb 2008;91(2):93-96.

52. Desmeules F, Minville L, Riederer B, et al. Acromio-Humeral Distance Variation Measured by Ultrasonography and Its Association with the Outcome of Rehabilitation for Shoulder Impingement Syndrome. *Clin J Sport Med.* Jul 2004;14(4):197-205.

53. Rushall BS. Swimming Energy Training in the 21st Century: The Justification for Radical Changes. *Swimming Science Bulletin.* 2013;39:1-55.

Manuscript 3

Examination of Participation and Shoulder Pain during the Training Season in Competitive Adolescent Swimmers

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Objective: To evaluate participation factors, pain scores, and shoulder injury during the training season and determine the relationship between these factors.

Design: Repeated-Measures Cohort.

Setting: Field Laboratory.

Participants: 45 adolescent competitive swimmers that were not currently experiencing any shoulder, neck, or back pain that limited their participation in sports activity were included in the study.

Assessment of Risk Factors: All participants were evaluated 3 times: once prior to the start of the swimming training season and then at 6 and 12 weeks following the baseline testing. At each session, participants completed a participation survey and 4 pain scores.

Main Outcome Measures: Total yardage during swim training and scores at each time on the following shoulder pain scales: Oxford Shoulder Scale (OSS), Shoulder Pain and Disability Index (SPADI), Penn Shoulder Scale (PENN), and Functional Arm Scale for Swimmers (FASS).

Results: Over the course of the training season, up to 71% of the adolescent swimmers reported experiencing mild shoulder pain, with some swimmers reporting moderate and severe pain. Swimmers completed 477,419 ± 103,829 yards during swim training. This yardage volume positively correlated to SPADI ($r=0.34$) and PENN ($r=0.37$) scores as measured at the 12-week (post-training season) testing session.

Conclusions: Over the course of the training season, a high percentage of swimmers reported pain with moderate disability and significant relationships were observed between total yardage performed and PENN and SPADI scores, which indicate training volume is a contributor to the development of shoulder pain and disability.

Key words: Swimmers, Shoulder Pain, Training Season

Word Count: 250/250

Introduction

To date, there has been limited work on training demands and shoulder pain in competitive adolescent swimmers.[1,2] These individuals participate on club swimming teams where training includes rigorous swim conditioning, dry-land training, and weight lifting. Due to the current popular theory of swim training, swimmers train at high volumes with a large number of yards being performed per practice with many practices a week.[3] Previous retrospective data found that competitive youth swimmers train 11 months out of the year and perform approximately 6,000-7,000 yards per practice during the training season[1] with little rest and time for muscle recovery from repetitive microtrauma.[4] This repetition can cause muscular fatigue, which may result in alterations in physical characteristics that may increase the risk of injury.[5] The high frequency and intensity of training often leads to "swimmer's shoulder" which is the general term for an overuse condition that leads to shoulder pain and inflammation of the rotator cuff and biceps tendon.[6]

A recent study reported that 26% of high school aged swimmers had significant shoulder pain, dissatisfaction, and/or disability.[7] Interfering shoulder pain has been reported in 45-91% of swimmers during their careers.[2,4,8,9] Shoulder pain in swimming is a major cause of missed practice and slower swim times.[10] One possible reason for this development may be because 90% of propulsive force in swimming comes from the upper extremity as the athlete must pull the body over the arm through the water.[9] Shoulder injury rates in competitive swimmers have been previously reported as 0.2 to 0.3 injuries per 1,000km,[11] indicating the influence of volume of training on shoulder injury rates. It has also previously been reported that 72% of adolescent swimmers report use of pain medication (either prescribed or over-the-counter) to manage their shoulder pain in order to participate in swim training.[1]

The culture of swimming dictates that shoulder pain is normal for competitive swimmers and it should be tolerated if they want to succeed. This mentality, which may have developed in collegiate and professional swimming, has been shown to exist in adolescent swimmers, as 85% of adolescent swimmers believe that mild shoulder pain is normal and should be tolerated in order to complete the necessary practice yardage.[1] While many athletes believe they should participate despite pain, it has been well established in the literature that pain alters motor control strategies and may contribute to neuromuscular adaptations, increasing the risk of injury development.[12] Specific to the shoulder, kinesthetic deficits have been found in the dominant limb of baseball pitchers who reported pain, despite not being diagnosed with a specific injury.[13] Further, it has been suggested that alterations in muscle firing patterns and inhibition of scapular stabilizing muscles due to shoulder pain may be a cause of scapular dyskinesia, which has been suggested as a risk factor for injury.[14,15] In swimming, previous literature has identified that individuals who reported pain had alterations in neck, scapular stabilizing and shoulder musculature that may contribute to decreased performance and increase the risk for the development of swimmer's shoulder. [16,17]

During the training season, competitive swimmers perform a large volume of yardage with high intensity practices in order to gain strength and power.[18] As the competition season approaches, swimmers begin to taper, which allows for muscle recovery and rest, ultimately optimizing physiological and psychological components to maximize performance in competitions.[19,20] Clinically, sports medicine professionals treat a high percentage of athletes reporting shoulder pain during the training season. Despite the high reporting of injuries during the training season, participation, pain and injury incidence in competitive adolescent swimmers has not been extensively evaluated in the literature. Therefore, the purpose of this study is to evaluate participation factors, pain scores, and shoulder injury during the swimming training season, as well as determine relationships that exist between these variables. This information will be beneficial to clinicians and coaches in understanding the training demands on these athletes and how the training relates to shoulder pain in competitive swimmers.

Methods

A cohort repeated measures research design was utilized. All participants in the study participated in three data collections: baseline (prior to the start of the swimming training season), 6 weeks post baseline assessment (mid-training season), and 12 weeks post baseline assessment (end of training season). At each testing session, participants completed a demographics, participation, and injury history questionnaire and completed 4 pain scales.

Participants

Participants were males and female competitive swimmers between the ages of 13 and 18 years old. Participants were included in the research study if they met all of the following criteria: member of a senior (top training level) team on their club team, regularly train at least 4 times per week, 1-2 hours each practice session and not currently experiencing back, neck or shoulder pain that limits their ability to participate. Swimming participants were excluded from the research study if they meet the following criteria: had less than 2 years of competitive swimming experience, had limitations in practice or were unable to complete practices fully due to pain, injury, or illness for more than 2 weeks during the training season, currently using any type of external, correctional posture device, or have a history of shoulder surgery.

Procedures

Prior to data collection, the primary investigator met with all potential participants and distributed information packets regarding the research study. Those interested in participating and their parents/guardians read and signed the informed consent form approved by a University Institutional Review Board. Participants completed a demographics form and 4 pain questions and returned the forms to the research team before starting practice for that day. Detailed procedures are discussed below.

At the initial data collection, participants completed a demographics form that included 3 sections: identification, swimming participation experience, and injury history and took approximately 10-15 minutes to complete. In the swimming participation section, the main focus was to quantify the practice habits of competitive adolescent swimmers in regards to total number of yards, practices per week, months per year of swimming, as well as gather information regarding dry-land training. Participants were also asked whether they experienced mild, moderate, or severe pain during the past year and how frequently. In this study, we operationally defined each type of pain and the definitions are included in **Table 1.**[1] These pain definitions were included in the survey and participants were able to ask the research team if there were any questions about these definitions. In addition, participants reported their shoulder injury history. At the 6-week and 12-week follow up sessions, participants completed demographics forms to report information regarding practices, injuries, and pain over the past 6-weeks only. Participants were able to determine number of practices per week and yardage per week by referencing swimming notebooks that each participant kept for their coaches. Reported participation numbers were verified by coaches of each of the swimming teams. From these surveys, yards per week, total yards, dry-land training were able to be calculated and presence of shoulder pain, injuries, and use of pain medication were quantified.

Several measures of subjective shoulder pain and functioning were used in order to evaluate baseline measures of shoulder pain and dysfunction and track how these change over the course of the training season. Participants filled out the surveys for both their dominant and non-dominant shoulders. Multiple types of shoulder evaluations were utilized in an attempt to capture acute pain, chronic pain, function and satisfaction in both daily living and during sport specific tasks. The four shoulder scales used for evaluation of shoulder pain and function were: Oxford Shoulder Scale (OSS), Shoulder Pain and Disability Index (SPADI), Penn Shoulder Scale (PENN), and Functional Arm Scale for Swimmers (FASS). Each of these shoulder scales is discussed in greater detail below.

The OSS is a 12-item patient report scale of pain and limitations during activities of daily living.[21] The survey asks participants to recall pain and limitations over the past 4 weeks. Participants reported pain or limitation on a scale of 0-4. Total scores range between 0-48, with greater OSS scores indicating greater dysfunction. Due to the agreement, reliability, and construct validity of the Oxford Shoulder Score with other previously validated assessments, it is an acceptable instrument to use for outcomes measures of shoulder pain and functioning [22].

The SPADI is 13-question self-report measure that evaluates the participant's pain and functioning at a specific time (data collection days).[23] Participants answered questions related to dimensions of pain and functioning. The participants responded to each item of the SPADI on a scale of 0-10, with 0 indicating no pain/difficulty and 10 indicating the worst pain imaginable/require help to complete task. A greater SPADI score indicates greater pain or impairment. The SPADI has been shown to be a reliable and valid measure [24,25] and is an effective tool for evaluating patients with improving or deteriorating conditions.[25]

The PENN is a composite score calculated from 24 questions that evaluate shoulder pain, satisfaction, and function.[26] A higher total score is indicative of greater shoulder pain and disability. The PENN has been demonstrated to be a valid and reliable measure for reporting shoulder pain in patients with various shoulder disorders.[26]

The FASS is a modification of the Functional Arm Scale for Throwers (FAST) which was previously developed as a region-specific self-report measure for throwing athletes to use to assess pain and limitations specific to the demands of the sport.[27] The FAST has been found to be positively correlated with self-reported pain and injury history in adolescent baseball players and may be a better representation of impairments in an active, youth population than traditional shoulder scores.[28] The FAST was modified to make it applicable to a swimming population for the development of the Functional Arm Scale for Swimmers (FASS). The FASS is scored on a Likert scale with associated points: 1 (least pain/symptoms/limitations) – 5 (most pain/symptoms/limitations). A total score is calculated by summing the responses to each of the questions.

Statistical Analysis

Completed surveys were de-identified and processed using Teleform (Autonomy Cardiff; Vista, California) document scanning and recognition software. The data were compiled into a spreadsheet for analysis. Descriptive analyses were run to determine average practice demands, presence of shoulder pain, shoulder injuries, and pain scores for each of the testing periods. Change scores were calculated for each pain subscale and scale as the difference between testing session 2 (6 week) and baseline and between testing session 3 (12 week) and baseline. A 2 x 2 with-in participants ANOVA (time-by-limb) was calculated to evaluate changes in each pain measure over the course of the training season. Finally, correlations were computed between the pain scores at the 6 weeks post-baseline assessment and yardage completed during this time and the pain scores at the 12 weeks post-baseline assessment and total yardage completed over the training season. An a priori alpha level was set at 0.05. All statistical calculations were performed using IBM SPSS V20 (IBM Inc., Chicago, Illinois).

Results

Forty-five competitive swimmers were evaluated at the baseline assessment. Over the 12-week training season, there was a 97% retention rate for swimmers. One swimmer withdrew from the study due to shoulder pain, which resulted in surgery. Therefore, 44 competitive swimmers (26 females/18males, age=16.5 ± 1.0 years, height=172.2 ± 12.9cm, mass=66.2 ± 10.2kg) with 9.4 ± 2.0 years of swimming experience were included in the final analysis. Mean participation values for the training season are presented in **Table 2**. Percentage of athletes reporting shoulder pain, shoulder injury, and medication use are reported in **Table 3.**

There were no significant interactions between limb and time or main effects for limb or time on any of the pain scales, indicating that there was not a significant change in reported pain levels during the course of the training season on any variable. P-values for the interaction and main effects are reported in **Table 4** and grand means of pain scores during the training season (collapsed for limb and time) are reported in **Table 5.**

There was a significant correlation between total yardage performed during the training season and SPADI scores (r_{84}=0.34, p=0.002) and total yardage and PENN scores (r_{84}=0.374, p<0.001). This finding demonstrates that as total yardage increased, so did SPADI and PENN scores- indicating greater shoulder pain and disability over the training season as measured by these scales. There were no significant correlations between yardage completed during the first 6-weeks of the training season and the OSS (p=0.75), SPADI (p=0.37), PENN (p=0.19), and FASS (p=0.56). There were no significant correlations between total yardage and OSS (p=0.19) and FASS (p=0.13).

Discussion

The purpose of this study was to describe practice demands and shoulder pain in competitive swimmers during the course of the training season to understand how these variables change, as well as may relate to the development of shoulder pain and injury in competitive swimmers.

Swimmers in the current study had an average of 9.4 years of competitive swimming participation experience and were training on the top training level for their club team. Previous research has identified that the earlier a swimmer begins participation in the sport, the greater the risk of development of swimmer's shoulder.[29,30] Because of the training demands and time expectations of youth swimmers, swimming is traditionally a sport of early specialization, where athletes focus solely on swimming.[31] In a 10-15 year swimming career, competitive swimmers will have 1-2 months of unscheduled practice time per year, resulting in significant exposure to the stresses of the swimming stroke which may cause adaptations of physical characteristics that increase the risk of injury.[4,32] In addition to age of specialization, the level of competition is also one of the greatest risk factors for the development of injury.[2,11,30] As competition level increases, so do the number of practice sessions and yards per session.[29,30] The increasing volume of swimming that comes with increased competition level has been associated with alterations in physical characteristics and shoulder pain. [2,11,30]

In the current study, swimmers swam approximately 42,000 yards per week in the first 6 weeks of the training season and 38,000 yards per week during the second 6 weeks of the training season. The average practice yardage seen in our study is comparable to previously reported practice in youth swimmers.[1,2] Based on the reported yardage from the adolescent swimmers, it can be estimated that these swimmers perform between 11,400-12,600 shoulder revolutions per arm per week and 136,800-151,200 revolutions per arm during the training season while completing their swim training. [32] This high demand on the shoulder during the training season has been theorized to be related to the development of shoulder pain and disability.

Significant correlations between total yardage of the training season and SPADI and PENN scores at the post-training season were observed. As there was an increase in total yardage performed during the training season, there was an increase in the total SPADI and PENN scores indicating greater reported pain and disability. These findings highlight the importance of training demands on the development of shoulder pain and disability and are in agreement with previous research evaluating the effect of yardage on swimmers pain and dysfunction.[2] On exam, swimmers with supraspinatus tendinopathy and pain have previously been found to have greater supraspinatus tendon thickness values that were associated with the number or hours swam and amount of yardage completed per week, indicating that the volume of training is related to the development of shoulder pain and injury.[2]

Over the course of the training season, more than half of the swimmers reported experiencing mild shoulder pain, with some swimmers reporting moderate and severe pain. Despite a high number of swimmers experiencing this pain, we were unable to identify significant changes over the training season in any of the pain scales that were used. Despite not finding significant changes over the course of the training season, there were a high percentage of swimmers that reported experiencing shoulder pain during the training season and a moderate amount of disability in the shoulders over the course of the training season. This finding is important, because it has previously been reported that individuals who reported pain had alterations in neck, scapular stabilizing and shoulder musculature that may contribute to decreased performance and increase the risk for the development of swimmer's shoulder. [16,17] The presence of shoulder pain may cause alterations in muscle activation and function that alters swimming mechanics. Previous research indicates that individuals with shoulder pain experience changes in muscle activation and freestyle stroke technique when compared to individuals without shoulder pain. [16,33] During the training season, up to 80% of practice is done using the freestyle stroke regardless of the primary stroke of the swimmer; therefore, alterations in the freestyle stroke could have significant implications on all swimmers regardless of stroke specialty.[4] Swimming with a freestyle stroke that includes biomechanical errors is thought to increase the time spent in the impingement position and may be a contributor to the development of shoulder pain. [16,34-37]

While significant correlations between total yardage and SPADI and PENN scores were observed, total yardage only explained 11% of the total SPADI score and 14% of the total PENN score. It is important for future research to identify other extrinsic factors that may be contributing to the development of shoulder pain to explain the variance in these pain scores, as well as the OSS and FASS. Future studies should attempt to evaluate changes in physiological variables following training, recovery factors, training intensities, and equipment use during training to gain a better understanding of how participation factors are influencing the development of shoulder pain in competitive adolescent swimmers.

In the current study, we evaluated the extrinsic risk factor of training volume, however, the interplay between the intrinsic and extrinsic factors of competitive swimmers **(Table 6)** may contribute to shoulder pain and injury**.** Alterations in the intrinsic risk factors may alter stroke biomechanics and/or participation variables such as yardage, equipment use, intensity of practice. Conversely, extrinsic risk factors may alter the intrinsic risk factors increasing shoulder stress. Overtime, this stress can result in the development of swimmer's shoulder, characterized by shoulder pain and dysfunction. Due to shoulder pain, alterations in technique and physical characteristics may occur and as swimmers continue to train through this, they enter a cycle of continuous shoulder pain. As such, it is important to understand each intrinsic and extrinsic risk factor and how it may influence other risk factors in order to provide evidence to help coaches and clinicians in designing training schedules and practices, as well as injury prevention programs.

There are several limitations of this study that should be acknowledged. First, participation was self-reported and verified by the coaches, but was not observed for each swimmer. This could have led to some inaccuracy in calculation of participation variables. In addition, the effort that each participant put into training could not be assessed. While this was not something that could be evaluated by the research team, the coaches, as part of their normal job responsibility, always encouraged athletes to give maximal effort and spoke individually with athletes that did not appear to be training as hard to change their behavior. Finally, we did not control for activities outside of team participation; however, no participants from our study were members of another sport team.

Conclusions

Competitive adolescent swimmers perform a tremendous amount of yardage during the training season as they build cardiorespiratory fitness and power. This level of training may cause adaptations of shoulder characteristics that increase the likelihood of the development of shoulder pain. Over the course of the training season, a high percentage of swimmers reported pain with moderate disability and significant relationships were observed between total yardage performed and PENN and SPADI scores. These findings indicate that training volume is a contributor to the development of shoulder pain and disability. Future research should focus on understanding other participation factors such as stroke biomechanics, training intensity, equipment use, and rest and recovery that may also significantly influence the development of shoulder pain and injury in competitive adolescent swimmers.

Table 1: Pain Definitions

Type of Pain	Definition
Mild	On a scale of 0-10, mild pain would be described as 0-4/10. It is only present while swimming and normal technique can be maintained during swimming.
Moderate	On a scale of 0-10, moderate pain would be described as 5-7/10. It is present while swimming and slight alterations of normal technique have to be made to get through practice. Pain is also present when out of the water but does not interfere with activities of daily life.
Severe	On a scale of 0-10, severe pain would be described as 8-10/10. It is sharp pain that is present while swimming and the stroke has to be significantly altered to complete practice. Pain is present when out of the water and interferes with activities of daily life.

Table 2: Mean Participation Values

	Baseline – 6 weeks post	6 weeks post – 12 weeks post	Total Training Season
Practices/Week	6.8 ± 1.1	6.6 ± 1.0	6.7 ± 1.0
Yards/Practice	6,181 ± 1,073	5,709 ± 1,225	5,948 ± 1,169
Yards/Week	42,068 ± 11,335	37,732 ± 10,082	39,925 ± 10,892
Total Yards	252,409 ± 68,010	226,395 ± 60,492	477,419 ± 103,829
Dry-land/Week	4.0 ± 1.0	3.3 ± 1.7	3.6 ± 1.6

Table 3: Percent of Swimmers Reporting Shoulder Pain During Training

	Baseline – 6 weeks post	6 weeks post – 12 weeks post
Mild Pain	70.5%	52.3%
Moderate Pain	31.8%	15.9%
Severe Pain	9.1%	4.5%
Shoulder Injury	2.2%	0%
Pain Medication Use	56.8%	43.2%

Table 4: Limb-by-Time Interaction and Main Effects on Changes in Pain Scores

	Limb-by-Time interaction	Time Main Effect	Limb Main Effect
OSS	0.34	0.62	0.87
SPADI	0.42	0.61	0.81
PENN	0.09	0.07	0.77
FASS	0.72	0.40	0.54

Table 5: Summary of Pain Scores

	Grand Mean	% Disability
OSS *(0-4 scale)*	2.0 ± 2.6	9.3%
SPADI *(0-130 scale)*	4.4 ± 6.5	3.4%
PENN *(0-100 scale)*	4.5 ± 6.8	4.5%
FASS *(24-120 scale)*	29.0 ± 7.6	5.2%

Table 6: Risk Factors for Shoulder Injury in Competitive Swimmers

Intrinsic Risk Factors	Extrinsic Risk Factors
Previous Injury	Competition Level
Hooked Acromion	Training Volume
Strength Imbalances	Stroke Biomechanics
Shoulder Laxity	Equipment Use
Scapular Dyskinesia	Rest/Recovery
Altered ROM	
Subacromial Space Distance	
Posture	
Supraspinatus Tendon Thickness	

REFERENCES

1. Hibberd EE, Myers JB. Practice Habits and Attitudes and Behaviors Concerning Shoulder Pain in High School Competitive Club Swimmers. *Clinical Journal of Sport Medicine.* Nov 2013;23(6):450-455.

2. Sein ML, Walton J, Linklater J, et al. Shoulder pain in elite swimmers: primarily due to swim-volume-induced supraspinatus tendinopathy. *Br J Sports Med.* Feb 2010;44(2):105-113.

3. Rushall BS. Swimming Energy Training in the 21st Century: The Justification for Radical Changes. *Swimming Science Bulletin.* 2013;39:1-55.

4. Beach ML, Whitney SL, Dickoff-Hoffman S. Relationship of shoulder flexibility, strength, and endurance to shoulder pain in competitive swimmers. *The Journal of orthopaedic and sports physical therapy.* 1992;16(6):262-268.

5. Su KP, Johnson MP, Gracely EJ, Karduna AR. Scapular rotation in swimmers with and without impingement syndrome: practice effects. *Medicine and science in sports and exercise.* Jul 2004;36(7):1117-1123.

6. Bak K, Magnusson SP. Shoulder strength and range of motion in symptomatic and pain-free elite swimmers. *Am J Sports Med.* Jul-Aug 1997;25(4):454-459.

7. Tate A, Turner GN, Knab SE, Jorgensen C, Strittmatter A, Michener LA. Risk factors associated with shoulder pain and disability across the lifespan of competitive swimmers. *J Athl Train.* Mar-Apr 2012;47(2):149-158.

8. Johnson D. In Swimming, shoulder the burden. *Sportcare Fitness.* 1988;May-June:24-30.

9. Pink MM, Tibone JE. The painful shoulder in the swimming athlete. *Orthop Clin North Am.* Apr 2000;31(2):247-261.

10. Weldon EJ, 3rd, Richardson AB. Upper extremity overuse injuries in swimming. A discussion of swimmer's shoulder. *Clin Sports Med.* Jul 2001;20(3):423-438.

11. Walker H, Gabbe B, Wajswelner H, Blanch P, Bennell K. Shoulder pain in swimmers: a 12-month prospective cohort study of incidence and risk factors. *Physical therapy in sport : official journal of the Association of Chartered Physiotherapists in Sports Medicine.* Nov 2012;13(4):243-249.

12. Le Pera D, Graven-Nielsen T, Valeriani M, et al. Inhibition of motor system excitability at cortical and spinal level by tonic muscle pain. *Clinical neurophysiology* Sep 2001;112(9):1633-1641.

13. Safran MR, Borsa PA, Lephart SM, Fu FH, Warner JJ. Shoulder proprioception in baseball pitchers. *J Shoulder Elbow Surg.* Sep-Oct 2001;10(5):438-444.

14. Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. *J Am Acad Orthop Surg.* Mar-Apr 2003;11(2):142-151.

15. Falla D, Farina D, Graven-Nielsen T. Experimental muscle pain results in reorganization of coordination among trapezius muscle subdivisions during repetitive shoulder flexion. *Experimental brain research.* Apr 2007;178(3):385-393.

16. Scovazzo ML, Browne A, Pink M, Jobe FW, Kerrigan J. The painful shoulder during freestyle swimming. An electromyographic cinematographic analysis of twelve muscles. *Am J Sports Med.* Nov-Dec 1991;19(6):577-582.

17. Hidalgo-Lozano A, Calderon-Soto C, Domingo-Camara A, Fernandez-de-Las-Penas C, Madeleine P, Arroyo-Morales M. Elite swimmers with unilateral shoulder pain demonstrate altered pattern of cervical muscle activation during a functional upper-limb task. *J Orthop Sports Phys Ther.* Jun 2012;42(6):552-558.

18. Salo D, Riewald S. *Complete Conditioning for Swimming*. Champaign, IL: Human Kinetics; 2008.

19. Mujika I, Padilla S. Detraining: loss of training-induced physiological and performance adaptations. Part II: Long term insufficient training stimulus. *Sports Med.* Sep 2000;30(3):145-154.

20. Mujika I, Padilla S. Scientific bases for precompetition tapering strategies. *Med Sci Sports Exerc.* Jul 2003;35(7):1182-1187.

21. Dawson J, Fitzpatrick R, Carr A. A self-administered questionnaire for assessment of symptoms and function of the shoulder. *The Journal of bone and joint surgery. American volume.* May 1998;80(5):766-767.

22. Ekeberg OM, Bautz-Holter E, Tveita EK, Keller A, Juel NG, Brox JI. Agreement, reliability and validity in 3 shoulder questionnaires in patients with rotator cuff disease. *BMC musculoskeletal disorders.* 2008;9:68.

23. Roach KE, Budiman-Mak E, Songsiridej N, Lertratanakul Y. Development of a shoulder pain and disability index. *Arthritis care and research : the official journal of the Arthritis Health Professions Association.* Dec 1991;4(4):143-149.

24. Breckenridge JD, McAuley JH. Shoulder Pain and Disability Index (SPADI). *Journal of physiotherapy.* 2011;57(3):197.

25. Roy JS, MacDermid JC, Woodhouse LJ. Measuring shoulder function: a systematic review of four questionnaires. *Arthritis and rheumatism.* May 15 2009;61(5):623-632.

26. Leggin BG, Michener LA, Shaffer MA, Brenneman SK, Iannotti JP, Williams GR, Jr. The Penn shoulder score: reliability and validity. *J Orthop Sports Phys Ther.* Mar 2006;36(3):138-151.

27. Ellery T, Sauers E, Snyder A, Bay R. The design and development of the Functional Arm Scale for Throwers. *J Athl Train.* 2008;43(2, Suppl):S51.

28. Sauers E, Thigpen C, Huxel K, Bay R. Relationships Between Self-Reported Pain and Injury History, the Functional Arm Scale for Thorwers (FAST) and the Disabilities of the Arm, Shoulder, and Hand (DASH) in Adolescent Baseball Pichers. Paper presented at: American Society of Shoulder and Elbow Therapists 2009 Annual Meeting2009.

29. Abgarov A, Fraser-Thomas J, Baker J. Understanding trends and risk factors of swimming-related injuries in varsity swimmers. *Clinical Kinesiology.* 2012;66(2):24-28.

30. Tate A, Turner GN, Knab SE, Jorgensen C, Strittmatter A, Michener LA. Risk factors associated with shoulder pain and disability across the lifespan of competitive swimmers. *J Athl Train.* Mar-Apr 2012;47(2):149-158.

31. Stocker D, Pink M, Jobe FW. Comparison of shoulder injury in collegiate- and master's-level swimmers. *Clin J Sport Med.* 1995;5(1):4-8.

32. Richardson AB, Jobe FW, Collins HR. The shoulder in competitive swimming. *Am J Sports Med.* May-Jun 1980;8(3):159-163.

33. Pink M, Perry J, Browne A, Scovazzo ML, Kerrigan J. The normal shoulder during freestyle swimming. An electromyographic and cinematographic analysis of twelve muscles. *Am J Sports Med.* Nov-Dec 1991;19(6):569-576.

34. Yanai T, Hay JG, Miller GF. Shoulder impingement in front-crawl swimming: I. a method to identify impingement. / Pathologie d'empietement affectant l'epaule lors de la pratique du crawl en natation. I : methode pour identifier le conflit. *Medicine & Science in Sports & Exercise.* 2000;32(1):21-29.

35. Yanai T, Hay JG. Shoulder impingement in front-crawl swimming: II. analysis of stroking technique. *Medicine & Science in Sports & Exercise.* 2000;32(1):30-40.

36. Johnson JN, Gauvin J, Fredericson M. Swimming Biomechanics and Injury Prevention. *Physcian and Sports Medicine.* 2003;31(1):41-48.

37. Heinlein SA, Cosgarea AJ. Biomechanical Considerations in the Competitive Swimmer's Shoulder. *Sports Health: A Multidisciplinary Approach.* November/December 2010 2010;2(6):519-525.

APPENDICES

Appendix 1A: Swimmers Demographics and Evaluation form for Pretest

Draft

Subject ID

Office use only

Youth Swimming Survey

Part 1: Identification

PLEASE USE CAPITAL LETTERS AND WRITE CLEARLY!

Today's Date

/ /

Month Day Year

First Name **MI** **Last Name**

Age (years) **Gender**

☐ Male ☐ Female

Part 2: Tell us about your Swimming Participation Experience

1. Including this year, how many years have you been swimming? (on ANY team)

2. How many years have you participated in competitive club swimming?

3. What strokes do you expect to compete in this year? (Check All That Apply)

☐ Freestyle ☐ Backstroke ☐ Breaststroke ☐ Butterfly ☐ IM

4. Of the strokes that you checked above, what is your primary competition stroke? (ONLY check one)

☐ Freestyle ☐ Backstroke ☐ Breaststroke ☐ Butterfly ☐ IM

5. What is your current primary distance training group on your club swimming team? (ONLY check one)

☐ Sprint ☐ Middle Distance ☐ Distance ☐ IM

Page 1 of 7

Draft

6. **On average, how many swimming practices do you complete per week? (not including dryland or weight sessions)**

☐ 1 practice	☐ 8 practices
☐ 2 practices	☐ 9 practices
☐ 3 practices	☐ 10 practices
☐ 4 practices	☐ 11 practices
☐ 5 practices	☐ 12 practices
☐ 6 practices	☐ 13 practices
☐ 7 practices	☐ 14 practices

7. **On average, how many days per week do you complete 2 or more practices per day?**

☐ 0 days	☐ 4 days
☐ 1 day	☐ 5 days
☐ 2 days	☐ 6 days
☐ 3 days	☐ 7 days

8. **On average, how many months per year do you complete swimming practice?**

☐ 1 month	☐ 7 months
☐ 2 months	☐ 8 months
☐ 3 months	☐ 9 months
☐ 4 months	☐ 10 months
☐ 5 months	☐ 11 months
☐ 6 months	☐ 12 months

9. **On average, how many yards per practice do you swim during your training season? (Do not include taper period)**

☐ Less than 1,000 yards	☐ 6,000 - 7,000 yards
☐ 1,000 - 2,000 yards	☐ 7,000 - 8,000 yards
☐ 2,000 - 3,000 yards	☐ 8,000 - 9,000 yards
☐ 3,000 - 4,000 yards	☐ 9,000 - 10,000 yards
☐ 4,000-5,000 yards	☐ More than 10,000 yards
☐ 5,000-6,000 yards	

10. **On average, how many dryland sessions do you complete per week?**

☐ 0 sessions	☐ 4 sessions
☐ 1 session	☐ 5 sessions
☐ 2 sessions	☐ 6 sessions
☐ 3 sessions	☐ More than 6 sessions

Draft

Part 2: Beliefs/Attitudes

1. Based on my knowledge of perfect technique, I swim freestyle properly during training and competition.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree ☐ I do not swim freestyle

2. Based on my knowledge of perfect technique, I swim backstroke properly during training and competition.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree ☐ I do not swim backstroke

3. Based on my knowledge of perfect technique, I swim breaststroke properly duing training and competition.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree ☐ I do not swim breaststroke

4. Based on my knowledge of perfect technique, I swim butterfly properly during training and competition.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree ☐ I do not swim butterfly

Based on the following definitions of pain severity, please answer the questions below.

- **Mild Pain:** On a scale of 0-10, mild pain would be described as 0-4/10. It is only present while swimming and normal technique can be maintained during swimming.

- **Moderate Pain:** On a scale of 0-10, moderate pain would be described as 5-7/10. It is present while swimming and slight alterations of normal technique have to be made to get through practice. Pain is also present when out of the water but does not interfere with activities of daily life.

- **Severe Pain:** On a scale of 0-10, severe pain would be described as 8-10/10. It is sharp pain that is present while swimming and the stroke has to be significantly altered to complete practice. Pain is present when out of the water and interferes with activities of daily life.

11. Mild pain is normal in swimming and should be tolerated in order to complete the necessary yards.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

12. Moderate pain is normal in swimming and should be tolerated in order to complete the necessary yards.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

13. Severe pain is normal in swimming and should be tolerated in order to complete the necessary yards.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

14. I do swim through mild shoulder pain in order to complete the necessary yards.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree ☐ Have not experienced mild pain

15. I do swim through moderate shoulder pain in order to complete the necessary yards.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree ☐ Have not experienced moderate pain

16. I should swim through severe shoulder pain in order to complete the necessary yards.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree ☐ Have not experienced severe pain

17. Taking time off from swimming due to injury is not a practical option if I want to succeed at a high level.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

18. I should swim through pain because it will go away during taper time.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree

Draft

Part 3: Injury History

Please answer questions 1-3 based on the definitions of mild, moderate, and severe pain provided on the previous page.

1. In the past 12 months, have you experienced mild pain in your shoulder while swimming ?

☐ Yes ☐ No

1a. If yes, how often did you experience mild shoulder pain while swimming?

☐ Less than 1 time per month ☐ 1 time per week
☐ 1 time per month ☐ 2-3 times per week
☐ 2-3 times per month ☐ More than 3 times per week

2. In the past 12 months, have you experienced moderate pain in your shoulder while swimming?

☐ Yes ☐ No

2a. If yes, how often did you experience moderate shoulder pain while swimming?

☐ Less than 1 time per month ☐ 1 time per week
☐ 1 time per month ☐ 2-3 times per week
☐ 2-3 times per month ☐ More than 3 times per week

3. In the past 12 months, have you experienced severe pain in your shoulder while swimming?

☐ Yes ☐ No

3a. If yes, how often did you experience severe shoulder pain while swimming?

☐ Less than 1 time per month ☐ 1 time per week
☐ 1 time per month ☐ 2-3 times per week
☐ 2-3 times per month ☐ More than 3 times per week

4. In the past 12 months, have you missed 1 or more practices due to shoulder pain?

☐ Yes ☐ No

4a. If yes, approximately, how many practices did you miss?

☐ 0 practices ☐ 20 - 30 practices
☐ 1 - 5 practices ☐ 30 - 40 practices
☐ 6 - 10 practices ☐ 40 -50 practices
☐ 10 - 15 practices ☐ More than 50 practices
☐ 16 - 20 practices

Draft

5. In the past 12 months, have you been limited from full practice in 1 or more practices due to shoulder pain? (<u>EXAMPLE</u>: biked instead of swimming or only kicked with no pulling due to pain)

☐ Yes ☐ No

5a. If yes, approximately, how many practices were you limited from full practice?

☐ 0 practices
☐ 1 - 5 practices
☐ 6 - 10 practices
☐ 10 - 15 practices
☐ 16 - 20 practices
☐ 20 - 30 practices
☐ 30 - 40 practices
☐ 40 -50 practices
☐ > 50 practices

6. In the past 12 months, have you taken pain relievers such as Ibuprofen (ex. Advil/Motrin), Acetaminophen (ex. Tylenol), Naproxen (ex. Aleve) or prescription pain medication so that you could swim?

☐ Yes ☐ No

6a. If yes, how often did you take pain relievers so that you could swim?

☐ <1 time per month
☐ 1 time per month
☐ 2-3 times per month
☐ 1 time per week
☐ 2-3 times per week
☐ > 3 times per week

6b. What type of pain relievers did you take so that you could swim?

☐ Not Applicable ☐ Over the Counter Medication ☐ Prescription Medication ☐ Other

Draft

In your shoulder, have you ever had a swimming-related injury that was sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your swimming career?

☐ No (You are finished with the questionnaire. Thank you!) ☐ Yes

If Yes, please check ALL the injuries you had that were sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your swimming career, and answer the questions to the right.

		When did you have the injury for the first time?	Did you see a doctor for this injury?	Did you get a surgery for this injury?
☐	Rotator cuff (tendonitis, strain, irritation, tear, impingement)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Labrum injury (tear, irritation, SLAP lesion)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Biceps tendon (tendonitis, subluxation, irritation)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Other muscle strain (not rotator cuff or biceps)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Bursitis	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Instability (Multi-directional, unidirectional)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Thoracic outlet syndrome	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Non-specific pain/soreness from overuse	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Other: Please specify	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes

You have completed the survey. Thank you for your participation!

62628

Youth Swimming Physical Characteristics Evaluation

ID (for office use only) ☐☐☐☐☐☐

First Name: ________ Last Name: ________

Event (check all that apply):
- ☐ Freestyle
- ☐ Butterfly
- ☐ Backstroke
- ☐ Breast_stroke
- ☐ IM

Distance:
- ☐ Sprint
- ☐ Sprint/mid-distance
- ☐ Mid-distance
- ☐ Mid-distance/distance
- ☐ Distance

Age: ____

Birthday: ____ / ____ / ____

Height: __ - ____ (ex. if 5'7" then "5-7")

Weight: ______ (lbs)

Hand dominance ☐ Right ☐ Left ☐ Both

Upper Extremity

FLEXIBILITY	**Right**		**Left**	
Flexion:	(1) ____	(deg)	(1) ____	(deg)
	(2) ____		(2) ____	
	(3) ____		(3) ____	
Supine ER @ 90	(1) ____	(deg)	(1) ____	(deg)
	(2) ____		(2) ____	
	(3) ____		(3) ____	
Supine IR @ 90:	(1) ____		(1) ____	
	(2) ____		(2) ____	
	(3) ____		(3) ____	
Posterior Shoulder Tightness:	(1) ____	(deg)	(1) ____	(deg)
	(2) ____		(2) ____	
	(3) ____		(3) ____	

Appendix 1B: Swimmers Demographics and Evaluation form for 6 and 12 week evaluation

47385

Subject ID

Office use only

Today's Date

/ /

Month Day Year

First Name MI Last Name

1. Over the past 6 weeks, how many swimming practices did you complete per week? (not including dryland or weight sessions)

- ☐ 1 practice
- ☐ 2 practices
- ☐ 3 practices
- ☐ 4 practices
- ☐ 5 practices
- ☐ 6 practices
- ☐ 7 practices
- ☐ 8 practices
- ☐ 9 practices
- ☐ 10 practices
- ☐ 11 practices
- ☐ 12 practices
- ☐ 13 practices
- ☐ 14 practices

2. Over the past 6 weeks, how many days per week did you complete 2 or more practices per day?

- ☐ 0 days
- ☐ 1 day
- ☐ 2 days
- ☐ 3 days
- ☐ 4 days
- ☐ 5 days
- ☐ 6 days
- ☐ 7 days

3. Over the past 6 weeks, how approximately many yards per practice did you swim?

- ☐ Less than 1,000 yards
- ☐ 1,000 - 2,000 yards
- ☐ 2,000 - 3,000 yards
- ☐ 3,000 - 4,000 yards
- ☐ 4,000-5,000 yards
- ☐ 5,000-6,000 yards
- ☐ 6,000 - 7,000 yards
- ☐ 7,000 - 8,000 yards
- ☐ 8,000 - 9,000 yards
- ☐ 9,000 - 10,000 yards
- ☐ More than 10,000 yards

4. Over the past 6 weeks, how many dryland sessions did you complete per week?

- ☐ 0 sessions
- ☐ 1 session
- ☐ 2 sessions
- ☐ 3 sessions
- ☐ 4 sessions
- ☐ 5 sessions
- ☐ 6 sessions
- ☐ More than 6 sessions

47385

Based on the following definitions of pain severity, please answer the questions below.

- **Mild Pain:** On a scale of 0-10, mild pain would be described as 0-4/10. It is only present while swimming and normal technique can be maintained during swimming.

- **Moderate Pain:** On a scale of 0-10, moderate pain would be described as 5-7/10. It is present while swimming and slight alterations of normal technique have to be made to get through practice. Pain is also present when out of the water but does not interfere with activities of daily life.

- **Severe Pain:** On a scale of 0-10, severe pain would be described as 8-10/10. It is sharp pain that is present while swimming and the stroke has to be significantly altered to complete practice. Pain is present when out of the water and interferes with activities of daily life.

1. In the past 6 weeks, I have swam through mild shoulder pain in order to complete the necessary yards.

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree ☐ Have not experienced mild pain

2. In the past 6 weeks, I have swam through moderate shoulder pain in order to complete the necessary

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree ☐ Have not experienced moderate pain

3. In the past 6 weeks, I have swam through severe shoulder pain in order to complete the necessary

☐ Strongly Disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly Agree ☐ Have not experienced severe pain

4. In the past 6 weeks, have you experienced mild pain in your shoulder while swimming ?

☐ Yes ☐ No

4a. If yes, how often did you experience mild shoulder pain while swimming?

☐ Less than 1 time per month ☐ 1 time per week

☐ 1 time per month ☐ 2-3 times per week

☐ 2-3 times per month ☐ More than 3 times per week

5. In the past 6 weeks, have you experienced moderate pain in your shoulder while swimming?

☐ Yes ☐ No

5a. If yes, how often did you experience moderate shoulder pain while swimming?

☐ Less than 1 time per month ☐ 1 time per week

☐ 1 time per month ☐ 2-3 times per week

☐ 2-3 times per month ☐ More than 3 times per week

47385

6. In the past 6 weeks, have you experienced severe pain in your shoulder while swimming?

☐ Yes ☐ No

6a. If yes, how often did you experience severe shoulder pain while swimming?

☐ Less than 1 time per month ☐ 1 time per week

☐ 1 time per month ☐ 2-3 times per week

☐ 2-3 times per month ☐ More than 3 times per week

7. In the past 6 weeks, have you missed 1 or more practices due to shoulder pain?

☐ Yes ☐ No

7a. If yes, approximately, how many practices did you miss?

☐ 0 practices ☐ 20 - 30 practices

☐ 1 - 5 practices ☐ 30 - 40 practices

☐ 6 - 10 practices ☐ 40 -50 practices

☐ 10 - 15 practices ☐ More than 50 practices

☐ 16 - 20 practices

8. In the past 6 weeks, have you been limited from full practice in 1 or more practices due to shoulder pain? (EXAMPLE: biked instead of swimming or only kicked with no pulling due to pain)

☐ Yes ☐ No

8a. If yes, approximately, how many practices were you limited from full practice?

☐ 0 practices ☐ 20 - 30 practices

☐ 1 - 5 practices ☐ 30 - 40 practices

☐ 6 - 10 practices ☐ 40 -50 practices

☐ 10 - 15 practices ☐ > 50 practices

☐ 16 - 20 practices

9. In the past 12 months, have you taken pain relievers such as Ibuprofen (ex. Advil/Motrin), Acetaminophen (ex. Tylenol), Naproxen (ex. Aleve) or prescription pain medication so that you could swim?

☐ Yes ☐ No

9a. If yes, how often did you take pain relievers so that you could swim?

☐ <1 time per month ☐ 1 time per week

☐ 1 time per month ☐ 2-3 times per week

☐ 2-3 times per month ☐ > 3 times per week

9b. What type of pain relievers did you take so that you could swim?

☐ Not Applicable ☐ Over the Counter Medication ☐ Prescription Medication ☐ Other

47385

In the past 6 weeks, have you ever had a swimming-related shoulder injury that was sufficiently bad that it stopped you from participating in practice or meets for at least 4 days?

☐ No ☐ Yes

If Yes, please check ALL the injuries you had that were sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your swimming career, and answer the questions to the right.

	Injury	When did you have the injury for the first time?	Did you see a doctor for this injury?	Did you get a surgery for this injury?
☐	Rotator cuff (tendonitis, strain, irritation, tear, impingement)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Labrum injury (tear, irritation, SLAP lesion)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Biceps tendon (tendonitis, subluxation, irritation)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Other muscle strain (not rotator cuff or biceps)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Bursitis	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Instability (Multi-directional, unidirectional)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Thoracic outlet syndrome	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Non-specific pain/soreness from overuse	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐	Other: Please specify	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes

47385

Please leave this section blank. It will be completed by the research team.

Dominant Arm: ☐ Right ☐ Left

		Right		Left
Internal rotation: (deg)	(1)		(1)	
	(2)		(2)	
	(3)		(3)	
External rotation: (deg)	(1)		(1)	
	(2)		(2)	
	(3)		(3)	
PST : (deg)	(1)		(1)	
	(2)		(2)	
	(3)		(3)	
Pec Minor:	(1)		(1)	
	(2)		(2)	
	(3)		(3)	

Height: ______ (cm)

Weight: ______.__

☐ Flag
Reason:

Appendix 1C: Controls Demographics and Evaluation form for Pretest

6162

Subject ID

Office use only

Sport and Injury Participation Survey

Part 1: Identification

PLEASE USE CAPITAL LETTERS AND WRITE CLEARLY!

Today's Date

☐☐ / ☐☐ / ☐☐

Month Day Year

First Name MI Last Name

Birthday

☐☐ / ☐☐ / ☐☐

Month Day Year

Gender

☐ Male ☐ Female

Part 2: Sports Participation

1. Are you currently participating on a lacrosse, baseball, softball, tennis, volleyball or swimming team?

☐ Yes ☐ No

**If you answered yes, you do not qualify for participation in this study.

2. Please check all the organized team/individual sports you participated in the past year. (This does not include sports you played as a part of your class activities or in pick up games). Please also indicate the number of years that you have been participating in this sport.

	Years of Participation		Years of Participation
☐ None		☐ Tennis	___
☐ Football	___	☐ Swimming	___
☐ Basketball	___	☐ Cross country	___
☐ Soccer	___	☐ Track	___
☐ Lacrosse	___	☐ Volleyball	___
☐ Wrestling	___	☐ Waterpolo	___
☐ Baseball	___	☐ Others (Please specify):	

6162

Based on the following definitions of pain severity, please answer the questions below.

- **Mild Pain:** On a scale of 0-10, mild pain would be described as 0-4/10. It is only present during activity and normal technique can be maintained.

- **Moderate Pain:** On a scale of 0-10, moderate pain would be described as 5-7/10. It is present during activity and slight alterations of normal technique have to be made to get through practice. Pain is also present not during practice but does not interfere with activities of daily life.

- **Severe Pain:** On a scale of 0-10, severe pain would be described as 8-10/10. It is sharp pain that is present during activity and the technique has to be significantly altered to complete practice. Pain is present when not practicing and interferes with activities of daily life.

6162

Part 3: Injury History

Please answer questions 1-3 based on the definitions of mild, moderate, and severe pain provided on the previous page.

1. In the past 12 months, have you experienced mild pain in your shoulder during sports participation ?

☐ Yes ☐ No

1a. If yes, how often did you experience mild shoulder pain during sports participation ?

☐ Less than 1 time per month ☐ 1 time per week
☐ 1 time per month ☐ 2-3 times per week
☐ 2-3 times per month ☐ More than 3 times per week

2. In the past 12 months, have you experienced moderate pain in your shoulder during sports participation?

☐ Yes ☐ No

2a. If yes, how often did you experience moderate shoulder pain during sports participation ?

☐ Less than 1 time per month ☐ 1 time per week
☐ 1 time per month ☐ 2-3 times per week
☐ 2-3 times per month ☐ More than 3 times per week

3. In the past 12 months, have you experienced severe pain in your shoulder during sports participation ?

☐ Yes ☐ No

3a. If yes, how often did you experience severe shoulder pain during sports participation?

☐ Less than 1 time per month ☐ 1 time per week
☐ 1 time per month ☐ 2-3 times per week
☐ 2-3 times per month ☐ More than 3 times per week

4. In the past 12 months, have you missed 1 or more practices due to shoulder pain?

☐ Yes ☐ No

4a. If yes, approximately, how many practices did you miss?

☐ 0 practices ☐ 20 - 30 practices
☐ 1 - 5 practices ☐ 30 - 40 practices
☐ 6 - 10 practices ☐ 40 -50 practices
☐ 10 - 15 practices ☐ More than 50 practices
☐ 16 - 20 practices

6162

5. In the past 12 months, have you been limited from full practice in 1 or more practices due to shoulder pain?

☐ Yes ☐ No

5a. If yes, approximately, how many practices were you limited from full practice?

☐ 0 practices
☐ 1 - 5 practices
☐ 6 - 10 practices
☐ 10 - 15 practices
☐ 16 - 20 practices
☐ 20 - 30 practices
☐ 30 - 40 practices
☐ 40 -50 practices
☐ > 50 practices

6. In the past 12 months, have you taken pain relievers such as Ibuprofen (ex. Advil/Motrin), Acetaminophen (ex. Tylenol), Naproxen (ex. Aleve) or prescription pain medication to aleviate shoulder pain so that you could participate in sports?

☐ Yes ☐ No

6a. If yes, how often did you take pain relievers so that you could participate in sports?

☐ <1 time per month
☐ 1 time per month
☐ 2-3 times per month
☐ 1 time per week
☐ 2-3 times per week
☐ > 3 times per week

6b. What type of pain relievers did you take for your shoulder pain so that you could participate in sports?

☐ Not Applicable ☐ Over the Counter Medication ☐ Prescription Medication ☐ Other

6162

In your shoulder, have you ever had a sports-related injury that was sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your athletic career?

☐ No ☐ Yes

If Yes, please check ALL the injuries you had that were sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your swimming career, and answer the questions to the right.

	When did you have the injury for the first time?	Did you see a doctor for this injury?	Did you get a surgery for this injury?
☐ Rotator cuff (tendonitis, strain, irritation, tear, impingement)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Labrum injury (tear, irritation, SLAP lesion)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Biceps tendon (tendonitis, subluxation, irritation)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Other muscle strain (not rotator cuff or biceps)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Bursitis	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Instability (Multi-directional, unidirectional)	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Thoracic outlet syndrome	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Non-specific pain/soreness from overuse	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Other: Please specify	(Month) (Year)	☐ No ☐ Yes	☐ No ☐ Yes

6162

Please fill out inside this box

First Name: | | | | | | | | | | Last Name: | | | | | | | | | | | |

Dominant Arm:: ☐ Right ☐ Left

Year in school: ☐ Junior High ☐ Freshman ☐ Sophomore ☐ Junior ☐ Senior

Are you Hispanic, Latino or Spanish origin? ☐ Yes ☐ No

What is your race? ☐ American Indian/Alaska Native
☐ Asian
☐ Native Hawaiian or Other Pacific Islander
☐ Black or African American
☐ White

		Right	Left
Internal rotation: (deg)	(1)	___	___
	(2)	___	___
	(3)	___	___
External rotation: (deg)	(1)	___	___
	(2)	___	___
	(3)	___	___
PST : (deg)	(1)	___	___
	(2)	___	___
	(3)	___	___
Pec Minor:	(1)	___	___
	(2)	___	___
	(3)	___	___

Height: ______ (cm)

Weight: ______ . __

☐ Flag
Reason:

☐ Parental Consent
☐ Child Assent
☐ Pubertal Development Scale
☐ Parents' Heights
☐ Survey
☐ Pain/Function Surveys
☐ Range of Motion
☐ Ultrasound
☐ Posture

Appendix 1D: Controls Demographics and Evaluation form for 6 and 12 week Evaluations

53986

Subject ID

☐☐☐☐☐☐☐

Office use only

In your shoulder, have you had a sports-related injury that was sufficiently bad that it stopped you from participating in practice or games for at least 7 days during the past 6 weeks?

☐ No ☐ Yes

If Yes, please check ALL the injuries you had that were sufficiently bad that it stopped you from participating in practice or games for at least 7 days during your swimming career, and answer the questions to the right.

	When did you have the injury for the first time?	Did you see a doctor for this injury?	Did you get a surgery for this injury?
☐ Rotator cuff (tendonitis, strain, irritation, tear, impingement)	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Labrum injury (tear, irritation, SLAP lesion)	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Biceps tendon (tendonitis, subluxation, irritation)	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Other muscle strain (not rotator cuff or biceps)	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Bursitis	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Instability (Multi-directional, unidirectional)	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Thoracic outlet syndrome	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Non-specific pain/soreness from overuse	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes
☐ Other: Please specify	☐☐ (Month) ☐☐☐☐ (Year)	☐ No ☐ Yes	☐ No ☐ Yes

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

53986

Based on the following definitions of pain severity, please answer the questions below.

- **Mild Pain:** On a scale of 0-10, mild pain would be described as 0-4/10. It is only present during activity and normal technique can be maintained.

- **Moderate Pain:** On a scale of 0-10, moderate pain would be described as 5-7/10. It is present during activity and slight alterations of normal technique have to be made to get through practice. Pain is also present not during practice but does not interfere with activities of daily life.

- **Severe Pain:** On a scale of 0-10, severe pain would be described as 8-10/10. It is sharp pain that is present during activity and the technique has to be significantly altered to complete practice. Pain is present when not practicing and interferes with activities of daily life.

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Please answer questions 1-3 based on the definitions of mild, moderate, and severe pain provided on the previous page.

1. In the past 6 weeks, have you experienced mild pain in your shoulder during sports participation ?

☐ Yes ☐ No

1a. If yes, how often did you experience mild shoulder pain during sports participation ?

☐ Less than 1 time per month ☐ 1 time per week
☐ 1 time per month ☐ 2-3 times per week
☐ 2-3 times per month ☐ More than 3 times per week

2. In the past 6 weeks, have you experienced moderate pain in your shoulder during sports participation? ?

☐ Yes ☐ No

2a. If yes, how often did you experience moderate shoulder pain during sports participation ?

☐ Less than 1 time per month ☐ 1 time per week
☐ 1 time per month ☐ 2-3 times per week
☐ 2-3 times per month ☐ More than 3 times per week

3. In the past 6 weeks, have you experienced severe pain in your shoulder during sports participation ?

☐ Yes ☐ No

3a. If yes, how often did you experience severe shoulder pain during sports participation?

☐ Less than 1 time per month ☐ 1 time per week
☐ 1 time per month ☐ 2-3 times per week
☐ 2-3 times per month ☐ More than 3 times per week

4. In the past 6 weeks, have you missed 1 or more practices due to shoulder pain?

☐ Yes ☐ No

4a. If yes, approximately, how many practices did you miss?

☐ 0 practices ☐ 20 - 30 practices
☐ 1 - 5 practices ☐ 30 - 40 practices
☐ 6 - 10 practices ☐ 40 -50 practices
☐ 10 - 15 practices ☐ More than 50 practices
☐ 16 - 20 practices

53986

5. In the past 6 weeks, have you been limited from full practice in 1 or more practices due to shoulder pain?

☐ Yes ☐ No

5a. If yes, approximately, how many practices were you limited from full practice?

☐ 0 practices
☐ 1 - 5 practices
☐ 6 - 10 practices
☐ 10 - 15 practices
☐ 16 - 20 practices
☐ 20 - 30 practices
☐ 30 - 40 practices
☐ 40 -50 practices
☐ > 50 practices

6. In the past 6 weeks, have you taken pain relievers such as Ibuprofen (ex. Advil/Motrin), Acetaminophen (ex. Tylenol), Naproxen (ex. Aleve) or prescription pain medication to aleviate shoulder pain so that you could participate in sports?

☐ Yes ☐ No

6a. If yes, how often did you take pain relievers so that you could participate in sports?

☐ <1 time per month
☐ 1 time per month
☐ 2-3 times per month
☐ 1 time per week
☐ 2-3 times per week
☐ > 3 times per week

6b. What type of pain relievers did you take for your shoulder pain so that you could participate in sports?

☐ Not Applicable ☐ Over the Counter Medication ☐ Prescription Medication ☐ Other

53986

PLEASE USE CAPITAL LETTERS AND WRITE CLEARLY!

Today's Date

__ __ / __ __ / __ __

Month Day Year

First Name MI Last Name

Internal rotation: (deg)	(1) ____	(1) ____	Height: ____ (cm)
	(2) ____	(2) ____	Weight: ____
	(3) ____	(3) ____	
External rotation: (deg)	(1) ____	(1) ____	☐ Flag Reason:
	(2) ____	(2) ____	
	(3) ____	(3) ____	
PST : (deg)	(1) ____	(1) ____	
	(2) ____	(2) ____	
	(3) ____	(3) ____	
Pec Minor:	(1) ____	(1) ____	
	(2) ____	(2) ____	
	(3) ____	(3) ____	

Appendix 2: Physical Maturity Assessment

ID: 2013 __ __ __ __(OFFICE USE)

Physical Maturity Assessment

In order to determine the physical maturity of your child, we are using 2 different assessments. The assessments include an estimate of skeletal maturity and puberty development scale. The estimate of skeletal maturity and puberty development scale are assessments that are based partially from responses you provide below. Please answer the questions below as accurately as possible. We respect the sensitivity of some of the information we are requesting below and want to ensure you that all information is strictly confidential and is only identified by an ID number assigned by the research team.

Estimate of Skeletal Maturity:

Percentage of mature height (an estimate of skeletal maturity) can be calculated by using athlete age, height, and weight and biological parent height. Current height of the athlete will be expressed as a percentage of his predicted mature height to provide an estimate of biological maturity status. Please provide an estimate of the height of the biological mother and father to the nearest half of an inch (ex. 5' 7.5).

- Height of Biological Mother: ____feet _____ . _____ inches (ex 5ft 7.5in)

- Height of Biological Father: ____feet _____ . _____ inches

(CONTINUES ON THE NEXT PAGE)

MALES (Females on next page)

Puberty Development Scale (to be completed by child with the help of a parent):

During adolescence, boys usually begin to experience many physical changes. The puberty development scale is a tool that is used to estimate a puberty stage. On the following page, please answer the questions to indicate changes that you have experienced.

1. **Have you noticed any skin changes like oily skin, pimples, or acne?**

   a. My skin has not yet started showing changes
   b. My skin has barely started showing changes
   c. My skin changes are definitely underway
   d. My skin changes are completed

2. **Boys your age often experience a sudden increase in their height called a "growth spurt. Would you say your growth spurt.....**

   a. Has not yet begun
   b. Has barely started
   c. Is definitely underway
   d. Seems completed

3. **Have you noticed a deepening of your voice?**

   a. My voice has not yet started changing
   b. My voice has barely started changing
   c. My voice change is definitely underway
   d. My voice change has been completed

4. **And how about the growth of underarm and pubic hair? Would you say it has....**

   a. Not started growing yet
   b. Has barely started
   c. Is definitely underway
   d. Seems completed

5. **Have you noticed an increase in your weight over the last few months?**

   a. I have not noticed an increase in weight
   b. I have barely noticed an increase in weight
   c. An increase in my body weight is definitely underway
   d. My body weight seems to have increased as much as it's going to

6. **Have you begun to grown hair on your face?**

   a. Not yet started growing hair
   b. Have barely started growing hair
   c. Facial hair growth is definitely underway
   d. Facial hair growth is complete
   a. _______ years old
   b. I have not started getting my monthly period yet

FEMALES (Males on previous page)

Puberty Development Scale (to be completed by child with the help of a parent):

During adolescence, girls usually begin to experience many physical changes. The puberty development scale is a tool that is used to estimate a puberty stage. On the following page, please answer the questions to indicate changes that you have experienced.

1. **Have you noticed any skin changes like oily skin, pimples, or acne?**

    a. My skin has not yet started showing changes
    b. My skin has barely started showing changes
    c. My skin changes are definitely underway
    d. My skin changes are completed

2. **Girls your age often experience a sudden increase in their height called a "growth spurt. Would you say your growth spurt.....**

    a. Has not yet begun
    b. Has barely started
    c. Is definitely underway
    d. Seems completed

3. **Have you noticed an increase in your weight over the last few months?**

    a. I have not noticed an increase in weight
    b. I have barely noticed an increase in weight
    c. An increase in my body weight is definitely underway
    d. My body weight seems to have increased as much as it's going to

4. **And how about the growth of underarm and pubic hair? Would you say it has....**

    a. Not started growing yet
    b. Has barely started
    c. Is definitely underway
    d. Seems completed

5. **Have your breasts begun to develop?**

    a. Not yet started breast development
    b. Have barely started breast development
    c. Breast development is definitely underway
    d. Breast development is complete

6. **How old were you when you had your first menstrual period?**

    a. _______ years old
    b. I have not started getting my monthly period yet

Appendix 3: Oxford Shoulder Score

1. During the past 4 weeks….				
How would you describe the **worst** pain you had from your shoulder?				
None ☐	Mild ☐	Moderate ☐	Severe ☐	Unbearable ☐

2. During the past 4 weeks….				
Have you had any trouble dressing yourself <u>because of your shoulder</u>?				
No trouble at all ☐	A little bit of trouble ☐	Moderate trouble ☐	Extreme Difficulty ☐	Impossible to do ☐

3. During the past 4 weeks….				
Have you had trouble getting in and out of a car or using public transportation <u>because of your shoulder</u>?				
No trouble at all ☐	A little bit of trouble ☐	Moderate trouble ☐	Extreme Difficulty ☐	Impossible to do ☐

4. During the past 4 weeks….				
Have you been able to use a knife and fork- <u>at the same time?</u>				
Yes Easily ☐	With little difficulty ☐	With Moderate difficulty ☐	With Extreme difficulty ☐	No, impossible ☐

5. During the past 4 weeks….				
Have you been able to carry your book bag normally?				
Yes Easily ☐	With little difficulty ☐	With Moderate difficulty ☐	With Extreme difficulty ☐	No, impossible ☐

6. During the past 4 weeks….				
Could you carry a tray containing a plate of food across a room?				
Yes Easily ☐	With little difficulty ☐	With Moderate difficulty ☐	With Extreme difficulty ☐	No, impossible ☐

7. During the past 4 weeks….

Could you brush/comb your hair?

Yes easily	With little difficulty	With Moderate difficulty	With Extreme difficulty	No, impossible
☐	☐	☐	☐	☐

8. During the past 4 weeks….

How would you describe the pain you <u>usually</u> had from your shoulder?

None	Very Mild	Mild	Moderate	Severe
☐	☐	☐	☐	☐

9. During the past 4 weeks….

Could you hang you clothes up in a wardrobe/closet, using the arm?

Yes easily	With little difficulty	With Moderate difficulty	With Extreme difficulty	No, impossible
☐	☐	☐	☐	☐e

10. During the past 4 weeks….

Have you been able to wash and dry your self under both arms?

Yes easily	With little difficulty	With Moderate difficulty	With Extreme difficulty	No, impossible
☐	☐	☐	☐	☐

11. During the past 4 weeks….

How much has <u>pain from your shoulder</u> interfered with your usual work (schoolwork/housework)?

Not at all	A little bit	Moderately	Greatly	Totally
☐	☐	☐	☐	☐

12. During the past 4 weeks….

Have you been troubled by <u>pain from your shoulder</u> in bed at night?

No nights	Only 1 or 2 nights	Some nights	Most nights	Every night
☐	☐	☐	☐	☐

Appendix 4: Shoulder Pain and Disability Index

Shoulder Pain and Disability Index (SPADI)

Please place a mark on the line that best represents your experience during the last week attributable to your shoulder problem.

Pain scale

How severe is your pain?

Circle the number that best describes your pain where: 0 = no pain and 10 = the worst pain imaginable.

At its worst?	0	1	2	3	4	5	6	7	8	9	10
When lying on the involved side?	0	1	2	3	4	5	6	7	8	9	10
Reaching for something on a high shelf?	0	1	2	3	4	5	6	7	8	9	10
Touching the back of your neck?	0	1	2	3	4	5	6	7	8	9	10
Pushing with the involved arm?	0	1	2	3	4	5	6	7	8	9	10

Disability scale

How much difficulty do you have?

Circle the number that best describes your experience where: 0 = no difficulty and 10 = so difficult it requires help.

Washing your hair?	0	1	2	3	4	5	6	7	8	9	10
Washing your back?	0	1	2	3	4	5	6	7	8	9	10
Putting on an undershirt or jumper?	0	1	2	3	4	5	6	7	8	9	10
Putting on a shirt that buttons down the front?	0	1	2	3	4	5	6	7	8	9	10
Putting on your pants?	0	1	2	3	4	5	6	7	8	9	10
Placing an object on a high shelf?	0	1	2	3	4	5	6	7	8	9	10
Carrying a heavy object of 10 pounds (4.5 kilograms)	0	1	2	3	4	5	6	7	8	9	10
Removing something from your back pocket?	0	1	2	3	4	5	6	7	8	9	10

Appendix 5: PENN Shoulder Score

PENN SHOULDER SCORE **Part I: Pain & Satisfaction:** Please circle the number closest to your level of pain or satisfaction	
Pain at rest with your arm by your side: 0 1 2 3 4 5 6 7 8 9 10 No Pain — Worst Pain Possible	office use only ______ (10 - # circled)
Pain with normal activities (eating, dressing, bathing): 0 1 2 3 4 5 6 7 8 9 10 No Pain — Worst Pain Possible	______ (10 - # circled) (score "0" if not applicable)
Pain with strenuous activities (reaching, lifting, pushing, pulling, throwing): 0 1 2 3 4 5 6 7 8 9 10 No Pain — Worst Pain Possible	______ (10 - # circled) (score "0" if not applicable)
PAIN SCORE:	**=___/30**
How satisfied are you with the current level of function of your shoulder? 0 1 2 3 4 5 6 7 8 9 10 Not Satisfied — Very Satisfied	**=___/10** (# circled)

PENN SHOULDER SCORE Part II: Function: Please circle the number that best describes the level of difficulty you might have performing each activity.	No difficulty	Some difficulty	Much difficulty	Can't do at all	Did not do before injury
1. Reach the small of your back to tuck in your shirt with your hand.	3	2	1	0	X
2. Wash the middle of your back/hook bra.	3	2	1	0	X
3. Perform necessary toileting activities.	3	2	1	0	X
4. Wash the back of opposite shoulder.	3	2	1	0	X
5. Comb hair.	3	2	1	0	X
6. Place hand behind head with elbow held straight out to the side.	3	2	1	0	X
7. Dress self (including put on coat and pull shirt of overhead.	3	2	1	0	X
8. Sleep on affected side.	3	2	1	0	X
9. Open a door with affected side.	3	2	1	0	X
10. Carry a bag of groceries with affected arm.	3	2	1	0	X
11. Carry a briefcase/small suitcase with affected arm.	3	2	1	0	X
12. Place a soup can (1-2 lbs.) on a shelf at shoulder level without bending elbow.	3	2	1	0	X
13. Place a one gallon container (8-10 lbs.) on a shelf at shoulder level without bending elbow.	3	2	1	0	X
14. Reach a shelf above your head without bending your elbow.	3	2	1	0	X
15. Place a soup can (1-2 lbs.) on a shelf overhead without bending your elbow.	3	2	1	0	X
16. Place a one gallon container (8-10 lbs.) on a shelf overhead without bending your elbow.	3	2	1	0	X
17. Perform usual sport/hobby.	3	2	1	0	X
18. Perform household chores (cleaning, laundry, cooking).	3	2	1	0	X
19. Throw overhand/swim/overhead racquet sports (circle all that apply to you)	3	2	1	0	X
20. Work full-time at your regular job.	3	2	1	0	X
SCORING: Total of columns = (a) Number of "X's" x 3 =____(b), 60 – ___(b) = ____ (c) (If no "X's" are circled, function score = total of columns) Function Score = ___(a) ÷ ___(c) = ___ x 60 = _____ of 60					

Appendix 6: Functional Arm Scale for Swimmers Adapted from Functional Arm Scale for Throwers [203]

Instructions: Please answer every question based on your arm condition during the last week by circling the number below the appropriate response. If you did not engage in an activity in the past week, please answer questions based on your estimate of how your arm condition would affect your ability to engage in the activity.

Section 1

Please circle the number that corresponds to your satisfaction level where C = completely, E = extremely, M = moderately, S = slightly, NS = not satisfied at all.

	C	E	M	S	NS
How satisfied are you with the way your arm is now functioning?	1	2	3	4	5

Section 2

Please circle the number that corresponds to your pain/discomfort level where N = none, M = mild, MO = moderate, S = severe, E = extreme

	N	M	MO	S	E
Following warm-up, how much pain do you have in your injured arm?	1	2	3	4	5
How much pain or discomfort do you have in your arm at night?	1	2	3	4	5
How much strength have you lost in your arm as a result of your arm injury?	1	2	3	4	5

Section 3

Please circle the number that best corresponds to each question where N = not at all, SL = slightly, M = moderately, SE = severely, E = extremely

	N	SL	M	SE	E
How much has your arm injury limited your ability to advance in your swimming event(s)?	1	2	3	4	5
How much have you modified your behavior to avoid making your arm injury worse?	1	2	3	4	5
Since your arm injury, do you have a more negative outlook on life?	1	2	3	4	5

How much does your arm injury interfere with things that are important, other than sports?	1	2	3	4	5
How stiff is your arm at night?	1	2	3	4	5
How much has your injury interfered with competition at swim meets?	1	2	3	4	5
How much are you limited when lifting your arm overhead to get dressed?	1	2	3	4	5

Section 4

Please circle the number that best corresponds with each question where NN = No, not at all, YSL = Yes, slightly, YM = Yes, moderately, YSE = Yes, severely, YE = Yes, extremely

	NN	YSL	YM	YSE	YE
Has your enjoyment of life decreased since your arm injury?	1	2	3	4	5
Has your arm injury decreased how long you can continue swimming during a single practice or game?	1	2	3	4	5
Have your sports accomplishments decreased since your arm injury?	1	2	3	4	5
Has your life been more stressful because of your arm injury?	1	2	3	4	5
How much pain or discomfort do you have in your arm with daily activities involving reaching?	1	2	3	4	5
How much pain or discomfort do you have in your arm if you use it for activities that last longer than 30 minutes?	1	2	3	4	5

Section 5

Please circle the number that best corresponds with each question where N = not at all, SL = slightly, M = moderately, SE = severely, U = unable to swim

	NN	YSL	YM	YSE	YE
How much has your arm injury limited your ability to swim freestyle?	1	2	3	4	5
How much has your arm injury limited your ability to swim butterfly?	1	2	3	4	5
How much has your arm injury limited your ability to swim	1	2	3	4	5

breaststroke?					
How much has your arm injury limited your ability to swim backstroke?	**1**	**2**	**3**	**4**	**5**
How weak does your arm feel during swimming?	**1**	**2**	**3**	**4**	**5**
How painful is your arm during "competition speed" swimming?	**1**	**2**	**3**	**4**	**5**
How painful is your arm during a 50-75% effort while swimming?	**1**	**2**	**3**	**4**	**5**

REFERENCES

1. U.S. Masters Swimming. 2013. http://www.usms.org.

2. Irick E. Student-Athlete Participation: 1981-1982 - 2011-2012. 2012. http://www.ncaapublications.com/productdownloads/PR2013.pdf.

3. 2012 USA Swimming Membership Demographics. *USA Swimming.* 2012. http://www.usaswimming.org/_Rainbow/Documents/ceb07df5-c623-49a9-ad4c-dc331707b3a4/Statistics-2012.pdf.

4. Johnson JN, Gauvin J, Fredericson M. Swimming Biomechanics and Injury Prevention. *Physcian and Sports Medicine.* 2003;31(1):41-48.

5. Hibberd EE, Myers JB. Practice Habits and Attitudes and Behaviors Concerning Shoulder Pain in High School Competitive Club Swimmers. *Clinical Journal of Sport Medicine.* Nov 2013;23(6):450-455.

6. Bak K, Magnusson SP. Shoulder strength and range of motion in symptomatic and pain-free elite swimmers. *Am J Sports Med.* Jul-Aug 1997;25(4):454-459.

7. Richardson AR. The biomechanics of swimming: the shoulder and knee. *Clin Sports Med.* Jan 1986;5(1):103-113.

8. Sein ML, Walton J, Linklater J, et al. Shoulder pain in elite swimmers: primarily due to swim-volume-induced supraspinatus tendinopathy. *Br J Sports Med.* Feb 2010;44(2):105-113.

9. McFarland EG, Wasik M. Injuries in female collegiate swimmers due to swimming and cross training. *Clin J Sport Med.* Jul 1996;6(3):178-182.

10. Johnson D. In Swimming, shoulder the burden. *Sportcare Fitness.* 1988;May-June:24-30.

11. Beach ML, Whitney SL, Dickoff-Hoffman S. Relationship of shoulder flexibility, strength, and endurance to shoulder pain in competitive swimmers. *The Journal of orthopaedic and sports physical therapy.* 1992;16(6):262-268.

12. Pink MM, Tibone JE. The painful shoulder in the swimming athlete. *Orthop Clin North Am.* Apr 2000;31(2):247-261.

13. Solem-Bertoft E, Thuomas KA, Westerberg CE. The influence of scapular retraction and protraction on the width of the subacromial space. An MRI study. *Clin Orthop Relat Res.* Nov 1993(296):99-103.

14. Deutsch A, Altchek DW, Schwartz E, Otis JC, Warren RF. Radiologic measurement of superior displacement of the humeral head in the impingement syndrome. *J Shoulder Elbow Surg.* May-Jun 1996;5(3):186-193.

15. Ludewig PM, Cook TM, Nawoczenski DA. Three-dimensional scapular orientation and muscle activity at selected positions of humeral elevation. *J Orthop Sports Phys Ther.* Aug 1996;24(2):57-65.

16. Wadsworth DJ, Bullock-Saxton JE. Recruitment patterns of the scapular rotator muscles in freestyle swimmers with subacromial impingement. *Int J Sports Med.* Nov 1997;18(8):618-624.

17. Graichen H, Bonel H, Stammberger T, et al. Three-dimensional analysis of the width of the subacromial space in healthy subjects and patients with impingement syndrome. *AJR Am J Roentgenol.* Apr 1999;172(4):1081-1086.

18. Lukasiewicz AC, McClure P, Michener L, Pratt N, Sennett B. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. *J Orthop Sports Phys Ther.* Oct 1999;29(10):574-583; discussion 584-576.

19. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Physical therapy.* Mar 2000;80(3):276-291.

20. Tyler TF, Nicholas SJ, Roy T, Gleim GW. Quantification of posterior capsule tightness and motion loss in patients with shoulder impingement. *Am J Sports Med.* Sep-Oct 2000;28(5):668-673.

21. Tsai NT, McClure PW, Karduna AR. Effects of muscle fatigue on 3-dimensional scapular kinematics. *Arch Phys Med Rehabil.* Jul 2003;84(7):1000-1005.

22. Karduna AR, Kerner PJ, Lazarus MD. Contact forces in the subacromial space: effects of scapular orientation. *J Shoulder Elbow Surg.* Jul-Aug 2005;14(4):393-399.

23. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med.* Mar 2006;34(3):385-391.

24. Santos MJ, Belangero WD, Almeida GL. The effect of joint instability on latency and recruitment order of the shoulder muscles. *J Electromyogr Kinesiol.* Apr 2007;17(2):167-175.

25. Hannula D, Thornton N, eds. *The Swim Coaching Bible*. Champaign: Human Kinetics; 2001.

26. Salo D, Riewald S. *Complete Conditioning for Swimming*. Champaign, IL: Human Kinetics; 2008.

27. Mujika I, Padilla S. Detraining: loss of training-induced physiological and performance adaptations. Part II: Long term insufficient training stimulus. *Sports Med.* Sep 2000;30(3):145-154.

28. Mujika I, Padilla S. Scientific bases for precompetition tapering strategies. *Med Sci Sports Exerc.* Jul 2003;35(7):1182-1187.

29. McMaster W. Assessment of the rotator cuff and a remedial exercise program for the aquatic athlete. *Med Sci Sports Exerc.* 1994;39:213-217.

30. Costill DL, Kovaleski J, Porter D, Kirwan J, Fielding R, King D. Energy expenditure during front crawl swimming: predicting success in middle-distance events. *Int J Sports Med.* Oct 1985;6(5):266-270.

31. Kebaetse M, McClure P, Pratt NA. Thoracic position effect on shoulder range of motion, strength, and three-dimensional scapular kinematics. *Arch Phys Med Rehabil.* Aug 1999;80(8):945-950.

32. Wang CH, McClure P, Pratt NE, Nobilini R. Stretching and strengthening exercises: their effect on three-dimensional scapular kinematics. *Arch Phys Med Rehabil.* Aug 1999;80(8):923-929.

33. Finley MA, Lee RY. Effect of sitting posture on 3-dimensional scapular kinematics measured by skin-mounted electromagnetic tracking sensors. *Arch Phys Med Rehabil.* Apr 2003;84(4):563-568.

34. Desmeules F, Minville L, Riederer B, Cote CH, Fremont P. Acromio-humeral distance variation measured by ultrasonography and its association with the outcome of rehabilitation for shoulder impingement syndrome. *Clin J Sport Med.* Jul 2004;14(4):197-205.

35. Azzoni R, Cabitza P, Parrini M. Sonographic evaluation of subacromial space. *Ultrasonics.* Apr 2004;42(1-9):683-687.

36. Pijls BG, Kok FP, Penning LI, Guldemond NA, Arens HJ. Reliability study of the sonographic measurement of the acromiohumeral distance in symptomatic patients. *J Clin Ultrasound.* Mar-Apr 2010;38(3):128-134.

37. Silva RT, Hartmann LG, Laurino CF, Bilo JP. Clinical and ultrasonographic correlation between scapular dyskinesia and subacromial space measurement among junior elite tennis players. *Br J Sports Med.* May 2010;44(6):407-410.

38. Cholewinski JJ, Kusz DJ, Wojciechowski P, Cielinski LS, Zoladz MP. Ultrasound measurement of rotator cuff thickness and acromio-humeral distance in the diagnosis of subacromial impingement syndrome of the shoulder. *Knee Surg Sports Traumatol Arthrosc.* Apr 2008;16(4):408-414.

39. Wang HK, Lin JJ, Pan SL, Wang TG. Sonographic evaluations in elite college baseball athletes. *Scandinavian journal of medicine & science in sports.* Feb 2005;15(1):29-35.

40. Richardson AB, Jobe FW, Collins HR. The shoulder in competitive swimming. *Am J Sports Med.* May-Jun 1980;8(3):159-163.

41. Weldon EJ, 3rd, Richardson AB. Upper extremity overuse injuries in swimming. A discussion of swimmer's shoulder. *Clin Sports Med.* Jul 2001;20(3):423-438.

42. McMaster WC. Shoulder injuries in competitive swimmers. *Clin Sports Med.* Apr 1999;18(2):349-359, vii.

43. Mountjoy M, Junge A, Alonso JM, et al. Sports injuries and illnesses in the 2009 FINA World Championships (Aquatics). *Br J Sports Med.* Jun 2010;44(7):522-527.

44. Bak K. The practical management of swimmer's painful shoulder: etiology, diagnosis, and treatment. *Clin J Sport Med.* Sep 2010;20(5):386-390.

45. Wolf BR, Ebinger AE, Lawler MP, Britton CL. Injury patterns in Division I collegiate swimming. *Am J Sports Med.* Oct 2009;37(10):2037-2042.

46. Walker H, Gabbe B, Wajswelner H, Blanch P, Bennell K. Shoulder pain in swimmers: a 12-month prospective cohort study of incidence and risk factors. *Physical therapy in sport : official journal of the Association of Chartered Physiotherapists in Sports Medicine.* Nov 2012;13(4):243-249.

47. Le Pera D, Graven-Nielsen T, Valeriani M, et al. Inhibition of motor system excitability at cortical and spinal level by tonic muscle pain. *Clinical neurophysiology* Sep 2001;112(9):1633-1641.

48. Safran MR, Borsa PA, Lephart SM, Fu FH, Warner JJ. Shoulder proprioception in baseball pitchers. *J Shoulder Elbow Surg.* Sep-Oct 2001;10(5):438-444.

49. Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. *J Am Acad Orthop Surg.* Mar-Apr 2003;11(2):142-151.

50. Falla D, Farina D, Graven-Nielsen T. Experimental muscle pain results in reorganization of coordination among trapezius muscle subdivisions during repetitive shoulder flexion. *Experimental brain research.* Apr 2007;178(3):385-393.

51. Scovazzo ML, Browne A, Pink M, Jobe FW, Kerrigan J. The painful shoulder during freestyle swimming. An electromyographic cinematographic analysis of twelve muscles. *Am J Sports Med.* Nov-Dec 1991;19(6):577-582.

52. Hidalgo-Lozano A, Calderon-Soto C, Domingo-Camara A, Fernandez-de-Las-Penas C, Madeleine P, Arroyo-Morales M. Elite swimmers with unilateral shoulder pain demonstrate altered pattern of cervical muscle activation during a functional upper-limb task. *J Orthop Sports Phys Ther.* Jun 2012;42(6):552-558.

53. Kennedy J, Hawkins R. Swimmers Shoulder. *The Physician and sportsmedicine.* 1974;2(4):34-38.

54. Wanivenhaus F, Fox AJ, Chaudhury S, Rodeo SA. Epidemiology of injuries and prevention strategies in competitive swimmers. *Sports health.* May 2012;4(3):246-251.

55. Neer CS, 2nd. Anterior acromioplasty for the chronic impingement syndrome in the shoulder. 1972. *The Journal of bone and joint surgery. American volume.* Jun 2005;87(6):1399.

56. Neer CS, 2nd. Impingement lesions. *Clin Orthop Relat Res.* Mar 1983(173):70-77.

57. Moore K, Dalley A. *Clinically Oriented Anatomy*. 5th ed. Philadelphia: Lipincott Williams & Wilkins; 2006.

58. Michener LA, McClure PW, Karduna AR. Anatomical and biomechanical mechanisms of subacromial impingement syndrome. *Clin Biomech.* Jun 2003;18(5):369-379.

59. Wilk KE, Obma P, Simpson CD, Cain EL, Dugas JR, Andrews JR. Shoulder injuries in the overhead athlete. *J Orthop Sports Phys Ther.* Feb 2009;39(2):38-54.

60. Fu FH, Harner CD, Klein AH. Shoulder impingement syndrome. A critical review. *Clin Orthop Relat Res.* Aug 1991(269):162-173.

61. Meyer A. The minuter anatomy of attrition lesions. *The Journal of bone and joint surgery. American volume.* 1931;13.

62. Bigliani LU, Morrison DS, April EW. The morphology of the acromion and its relationship to rotator cuff tears. *Orthop. Trans.* 1986;10.

63. MacGillivray JD, Fealy S, Potter HG, O'Brien SJ. Multiplanar analysis of acromion morphology. *Am J Sports Med.* Nov-Dec 1998;26(6):836-840.

64. Cohen RB, Williams GR, Jr. Impingement syndrome and rotator cuff disease as repetitive motion disorders. *Clin Orthop Relat Res.* Jun 1998(351):95-101.

65. Hardy DC, Vogler JB, 3rd, White RH. The shoulder impingement syndrome: prevalence of radiographic findings and correlation with response to therapy. *AJR Am J Roentgenol.* Sep 1986;147(3):557-561.

66. Hawkins RJ, Misamore GW, Hobeika PE. Surgery for full-thickness rotator-cuff tears. *The Journal of bone and joint surgery. American volume.* Dec 1985;67(9):1349-1355.

67. Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. *J Orthop Sports Phys Ther.* Feb 2009;39(2):90-104.

68. Endo K, Ikata T, Katoh S, Takeda Y. Radiographic assessment of scapular rotational tilt in chronic shoulder impingement syndrome. *J Orthop Sci.* 2001;6(1):3-10.

69. Thomas SJ, Swanik KA, Swanik CB, Kelly JDt. Internal rotation deficits affect scapular positioning in baseball players. *Clin Orthop Relat Res.* Jun 2010;468(6):1551-1557.

70. Harryman DT, 2nd, Sidles JA, Clark JM, McQuade KJ, Gibb TD, Matsen FA, 3rd. Translation of the humeral head on the glenoid with passive glenohumeral motion. *The Journal of bone and joint surgery. American volume.* Oct 1990;72(9):1334-1343.

71. Laudner KG, Sipes R. The Incidence of Shoulder Injury among Collegiate Overhead Athletes. *Journal of Intercollegiate Sport.* 2009(2):260-268.

72. Walch G, Boileau P, Noel E, Donell ST. Impingement of the deep surface of the supraspinatus tendon on the posterosuperior glenoid rim: An arthroscopic study. *J Shoulder Elbow Surg.* Sep 1992;1(5):238-245.

73. Bigliani LU, Ticker JB, Flatow EL, Soslowsky LJ, Mow VC. The relationship of acromial architecture to rotator cuff disease. *Clin Sports Med.* Oct 1991;10(4):823-838.

74. Mudge MK, Wood VE, Frykman GK. Rotator cuff tears associated with os acromiale. *The Journal of bone and joint surgery. American volume.* Mar 1984;66(3):427-429.

75. Petersson CJ, Gentz CF. Ruptures of the supraspinatus tendon. The significance of distally pointing acromioclavicular osteophytes. *Clin Orthop Relat Res.* Apr 1983(174):143-148.

76. Voight ML, Thomson BC. The role of the scapula in the rehabilitation of shoulder injuries. *J Athl Train.* Jul 2000;35(3):364-372.

77. Carpenter JE, Flanagan CL, Thomopoulos S, Yian EH, Soslowsky LJ. The effects of overuse combined with intrinsic or extrinsic alterations in an animal model of rotator cuff tendinosis. *Am J Sports Med.* Nov-Dec 1998;26(6):801-807.

78. Abate M, Silbernagel KG, Siljeholm C, et al. Pathogenesis of tendinopathies: inflammation or degeneration? *Arthritis research & therapy.* 2009;11(3):235.

79. Soslowsky LJ, Thomopoulos S, Tun S, et al. Neer Award 1999. Overuse activity injures the supraspinatus tendon in an animal model: a histologic and biomechanical study. *J Shoulder Elbow Surg.* Mar-Apr 2000;9(2):79-84.

80. Dela Rosa TL, Wang AW, Zheng MH. Tendinosis of the Rotator Cuff: A Review. *Journal of Musculoskeletal Research.* 2001;5(3):143-158.

81. Ellman H. Diagnosis and treatment of incomplete rotator cuff tears. *Clin Orthop Relat Res.* May 1990(254):64-74.

82. Churgay CA. Diagnosis and treatment of biceps tendinitis and tendinosis. *American family physician.* Sep 1 2009;80(5):470-476.

83. Nho SJ, Strauss EJ, Lenart BA, et al. Long head of the biceps tendinopathy: diagnosis and management. *J Am Acad Orthop Surg.* Nov 2010;18(11):645-656.

84. Vangsness CT, Jr., Jorgenson SS, Watson T, Johnson DL. The origin of the long head of the biceps from the scapula and glenoid labrum. An anatomical study of 100 shoulders. *The Journal of bone and joint surgery. British volume.* Nov 1994;76(6):951-954.

85. Clark JM, Harryman DT, 2nd. Tendons, ligaments, and capsule of the rotator cuff. Gross and microscopic anatomy. *The Journal of bone and joint surgery. American volume.* Jun 1992;74(5):713-725.

86. Post M, Benca P. Primary tendinitis of the long head of the biceps. *Clin Orthop Relat Res.* Sep 1989(246):117-125.

87. McGough RL, Debski RE, Taskiran E, Fu FH, Woo SL. Mechanical properties of the long head of the biceps tendon. *Knee Surg Sports Traumatol Arthrosc.* 1996;3(4):226-229.

88. Warner JJ, McMahon PJ. The role of the long head of the biceps brachii in superior stability of the glenohumeral joint. *The Journal of bone and joint surgery. American volume.* Mar 1995;77(3):366-372.

89. Sakurai G, Ozaki J, Tomita Y, Nishimoto K, Tamai S. Electromyographic analysis of shoulder joint function of the biceps brachii muscle during isometric contraction. *Clin Orthop Relat Res.* Sep 1998(354):123-131.

90. Malicky DM, Soslowsky LJ, Blasier RB, Shyr Y. Anterior glenohumeral stabilization factors: progressive effects in a biomechanical model. *J Orthop Res.* Mar 1996;14(2):282-288.

91. Nidecker A, Guckel C, von Hochstetter A. Imaging the long head of biceps tendon--a pictorial essay emphasizing magnetic resonance. *Eur J Radiol.* Nov 1997;25(3):177-187.

92. Pagnani MJ, Deng XH, Warren RF, Torzilli PA, O'Brien SJ. Role of the long head of the biceps brachii in glenohumeral stability: a biomechanical study in cadavera. *J Shoulder Elbow Surg.* Jul-Aug 1996;5(4):255-262.

93. Rodosky MW, Harner CD, Fu FH. The role of the long head of the biceps muscle and superior glenoid labrum in anterior stability of the shoulder. *Am J Sports Med.* Jan-Feb 1994;22(1):121-130.

94. McMahon PJ, Burkart A, Musahl V, Debski RE. Glenohumeral translations are increased after a type II superior labrum anterior-posterior lesion: a cadaveric study of severity of passive stabilizer injury. *J Shoulder Elbow Surg.* Jan-Feb 2004;13(1):39-44.

95. Sethi N, Wright R, Yamaguchi K. Disorders of the long head of the biceps tendon. *J Shoulder Elbow Surg.* Nov-Dec 1999;8(6):644-654.

96. Eakin CL, Faber KJ, Hawkins RJ, Hovis WD. Biceps tendon disorders in athletes. *J Am Acad Orthop Surg.* Sep-Oct 1999;7(5):300-310.

97. Yanai T, Hay JG. Shoulder impingement in front-crawl swimming: II. Analysis of stroking technique. *Med Sci Sports Exerc.* Jan 2000;32(1):30-40.

98. Glousman R, Jobe F, Tibone J, Moynes D, Antonelli D, Perry J. Dynamic electromyographic analysis of the throwing shoulder with glenohumeral instability. *The Journal of bone and joint surgery. American volume.* Feb 1988;70(2):220-226.

99. Arroyo JS, Hershon SJ, Bigliani LU. Special considerations in the athletic throwing shoulder. *Orthop Clin North Am.* Jan 1997;28(1):69-78.

100. Krupp RJ, Kevern MA, Gaines MD, Kotara S, Singleton SB. Long head of the biceps tendon pain: differential diagnosis and treatment. *J Orthop Sports Phys Ther.* Feb 2009;39(2):55-70.

101. Barber FA, Field LD, Ryu RK. Biceps tendon and superior labrum injuries: decision making. *Instructional course lectures.* 2008;57:527-538.

102. Meeuwisse WH, Tyreman H, Hagel B, Emery C. A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clin J Sport Med.* May 2007;17(3):215-219.

103. Abgarov A, Fraser-Thomas J, Baker J. Understanding trends and risk factors of swimming-related injuries in varsity swimmers. *Clinical Kinesiology.* 2012;66(2):24-28.

104. Tate A, Turner GN, Knab SE, Jorgensen C, Strittmatter A, Michener LA. Risk factors associated with shoulder pain and disability across the lifespan of competitive swimmers. *J Athl Train.* Mar-Apr 2012;47(2):149-158.

105. Stocker D, Pink M, Jobe FW. Comparison of shoulder injury in collegiate- and master's-level swimmers. *Clin J Sport Med.* 1995;5(1):4-8.

106. Worland RL, Lee D, Orozco CG, SozaRex F, Keenan J. Correlation of age, acromial morphology, and rotator cuff tear pathology diagnosed by ultrasound in asymptomatic patients. *J South Orthop Assoc.* Spring 2003;12(1):23-26.

107. Payne LZ, Deng XH, Craig EV, Torzilli PA, Warren RF. The combined dynamic and static contributions to subacromial impingement. A biomechanical analysis. *Am J Sports Med.* Nov-Dec 1997;25(6):801-808.

108. Epstein RE, Schweitzer ME, Frieman BG, Fenlin JM, Jr., Mitchell DG. Hooked acromion: prevalence on MR images of painful shoulders. *Radiology.* May 1993;187(2):479-481.

109. Toivonen DA, Tuite MJ, Orwin JF. Acromial structure and tears of the rotator cuff. *J Shoulder Elbow Surg.* Sep-Oct 1995;4(5):376-383.

110. Chambler AF, Pitsillides AA, Emery RJ. Acromial spur formation in patients with rotator cuff tears. *J Shoulder Elbow Surg.* Jul-Aug 2003;12(4):314-321.

111. Hawley JA, Williams MM. Relationship between upper body anaerobic power and freestyle swimming performance. *Int J Sports Med.* Feb 1991;12(1):1-5.

112. Bak K, Fauno P. Clinical findings in competitive swimmers with shoulder pain. *Am J Sports Med.* Mar-Apr 1997;25(2):254-260.

113. Ramsi M, Swanik K, Swanik C, Straub S, Mattacola C. Shoulder-Rotator Strength of High School Swimmers Over the Course of a Competitive Season. *J Sport Rehabil.* 2004;13(1):9-18.

114. Myers JB, Hwang JH, Pasquale MR, Blackburn JT, Lephart SM. Rotator cuff coactivation ratios in participants with subacromial impingement syndrome. *Journal of science and medicine in sport* Nov 2009;12(6):603-608.

115. Halder AM, Zhao KD, Odriscoll SW, Morrey BF, An KN. Dynamic contributions to superior shoulder stability. *Journal of orthopaedic research.* Mar 2001;19(2):206-212.

116. von Eisenhart-Rothe R, Matsen FA, 3rd, Eckstein F, Vogl T, Graichen H. Pathomechanics in atraumatic shoulder instability: scapular positioning correlates with humeral head centering. *Clin Orthop Relat Res.* Apr 2005(433):82-89.

117. Bassett RW, Browne AO, Morrey BF, An KN. Glenohumeral muscle force and moment mechanics in a position of shoulder instability. *J Biomech.* 1990;23(5):405-415.

118. Su KP, Johnson MP, Gracely EJ, Karduna AR. Scapular rotation in swimmers with and without impingement syndrome: practice effects. *Medicine and science in sports and exercise.* Jul 2004;36(7):1117-1123.

119. Huffman GR, Tibone JE, McGarry MH, Phipps BM, Lee YS, Lee TQ. Path of glenohumeral articulation throughout the rotational range of motion in a thrower's shoulder model. *Am J Sports Med.* Oct 2006;34(10):1662-1669.

120. Clabbers KM, Kelly JD, Bader D, et al. Effect of posterior capsule tightness on glenohumeral translation in the late-cocking phase of pitching. *J Sport Rehabil.* Feb 2007;16(1):41-49.

121. Grossman MG, Tibone JE, McGarry MH, Schneider DJ, Veneziani S, Lee TQ. A cadaveric model of the throwing shoulder: a possible etiology of superior labrum anterior-to-posterior lesions. *The Journal of bone and joint surgery. American volume.* Apr 2005;87(4):824-831.

122. Yanai T, Hay JG, Miller GF. Shoulder impingement in front-crawl swimming: I. A method to identify impingement. *Med Sci Sports Exerc.* Jan 2000;32(1):21-29.

123. Jobe FW, Kvitne RS, Giangarra CE. Shoulder pain in the overhand or throwing athlete. The relationship of anterior instability and rotator cuff impingement. *Orthop Rev.* Sep 1989;18(9):963-975.

124. Mihata T, Lee Y, McGarry MH, Abe M, Lee TQ. Excessive humeral external rotation results in increased shoulder laxity. *Am J Sports Med.* Jul-Aug 2004;32(5):1278-1285.

125. Illyes A, Kiss RM. Kinematic and muscle activity characteristics of multidirectional shoulder joint instability during elevation. *Knee Surg Sports Traumatol Arthrosc.* Jul 2006;14(7):673-685.

126. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part III: The SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. *Arthroscopy.* Jul-Aug 2003;19(6):641-661.

127. Karduna AR, McClure PW, Michener LA, Sennett B. Dynamic measurements of three-dimensional scapular kinematics: a validation study. *J Biomech Eng.* Apr 2001;123(2):184-190.

128. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Scapular position and orientation in throwing athletes. *Am J Sports Med.* Feb 2005;33(2):263-271.

129. Oyama S, Myers JB, Wassinger CA, Daniel Ricci R, Lephart SM. Asymmetric resting scapular posture in healthy overhead athletes. *J Athl Train.* Oct-Dec 2008;43(6):565-570.

130. Borich MR, Bright JM, Lorello DJ, Cieminski CJ, Buisman T, Ludewig PM. Scapular angular positioning at end range internal rotation in cases of glenohumeral internal rotation deficit. *J Orthop Sports Phys Ther.* Dec 2006;36(12):926-934.

131. Kibler WB. The role of the scapula in athletic shoulder function. *Am J Sports Med.* Mar-Apr 1998;26(2):325-337.

132. Laudner KG, Williams JG. The relationship between latissimus dorsi stiffness and altered scapular kinematics among asymptomatic collegiate swimmers. *Physical Therapy in Sport.* 2013;14(1):50-53.

133. Hibberd EE, Oyama S, Spang JT, Prentice W, Myers JB. Effect of a 6-week strengthening program on shoulder and scapular-stabilizer strength and scapular kinematics in division I collegiate swimmers. *J Sport Rehabil.* Aug 2012;21(3):253-265.

134. Laudner KG, Myers JB, Pasquale MR, Bradley JP, Lephart SM. Scapular dysfunction in throwers with pathologic internal impingement. *J Orthop Sports Phys Ther.* Jul 2006;36(7):485-494.

135. Pink M, Perry J, Browne A, Scovazzo ML, Kerrigan J. The normal shoulder during freestyle swimming. An electromyographic and cinematographic analysis of twelve muscles. *Am J Sports Med.* Nov-Dec 1991;19(6):569-576.

136. Kibler WB, Sciascia A. Current concepts: scapular dyskinesis. *Br J Sports Med.* Apr 2010;44(5):300-305.

137. Crockett HC, Gross LB, Wilk KE, et al. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *Am J Sports Med.* Jan-Feb 2002;30(1):20-26.

138. Bigliani LU, Codd TP, Connor PM, Levine WN, Littlefield MA, Hershon SJ. Shoulder motion and laxity in the professional baseball player. *Am J Sports Med.* Sep-Oct 1997;25(5):609-613.

139. Brown LP, Niehues SL, Harrah A, Yavorsky P, Hirshman HP. Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players. *Am J Sports Med.* Nov-Dec 1988;16(6):577-585.

140. Ellenbecker TS, Roetert EP, Bailie DS, Davies GJ, Brown SW. Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers. *Med Sci Sports Exerc.* Dec 2002;34(12):2052-2056.

141. Reagan KM, Meister K, Horodyski MB, Werner DW, Carruthers C, Wilk K. Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. *Am J Sports Med.* May-Jun 2002;30(3):354-360.

142. Thomas SJ, Swanik CB, Higginson JS, et al. A bilateral comparison of posterior capsule thickness and its correlation with glenohumeral range of motion and scapular upward rotation in collegiate baseball players. *J Shoulder Elbow Surg.* Jul 2011;20(5):708-716.

143. Hibberd E, Oyama S, Tatman J, Myers J. Domint-limb Range of Motion Adaptation in Collegiate Baseball and Softball Position Playeres. *Journal of Athletic Training.* In Press.

144. Morgan CD, Burkhart SS, Palmeri M, Gillespie M. Type II SLAP lesions: three subtypes and their relationships to superior instability and rotator cuff tears. *Arthroscopy.* Sep 1998;14(6):553-565.

145. Dines JS, Frank JB, Akerman M, Yocum LA. Glenohumeral internal rotation deficits in baseball players with ulnar collateral ligament insufficiency. *Am J Sports Med.* Mar 2009;37(3):566-570.

146. Spigelman T. Identifying and Assessing Glenohumeral Internal-Rotation Deficit. *Athletic Therapy Today.* 2006;11(3):32-34.

147. Sanders R, Thow J, Fairweather M. Asymmetries in Swimming: Where Do They Come from? *J. Swimming Research.* 2011;18.

148. Jansson A, Saartok T, Werner S, Renstrom P. Evaluation of general joint laxity, shoulder laxity and mobility in competitive swimmers during growth and in normal controls. *Scandinavian journal of medicine & science in sports.* Jun 2005;15(3):169-176.

149. Riemann BL, Witt J, Davies GJ. Glenohumeral joint rotation range of motion in competitive swimmers. *J Sports Sci.* Aug 2011;29(11):1191-1199.

150. Osbahr DC, Cannon DL, Speer KP. Retroversion of the humerus in the throwing shoulder of college baseball pitchers. *Am J Sports Med.* May-Jun 2002;30(3):347-353.

151. Kronberg M, Brostrom LA, Soderlund V. Retroversion of the humeral head in the normal shoulder and its relationship to the normal range of motion. *Clin Orthop Relat Res.* Apr 1990(253):113-117.

152. Hung CJ, Hsieh CL, Yang PL, Lin JJ. Relationships between posterior shoulder muscle stiffness and rotation in patients with stiff shoulder. *Journal* *of rehabilitation medicine : official journal of the UEMS European Board of Physical and Rehabilitation Medicine.* Mar 2010;42(3):216-220.

153. Laudner KG, Sipes RC, Wilson JT. The acute effects of sleeper stretches on shoulder range of motion. *J Athl Train.* Jul-Aug 2008;43(4):359-363.

154. Oyama S, Goerger CP, Goerger BM, Lephart SM, Myers JB. Effects of non-assisted posterior shoulder stretches on shoulder range of motion among collegiate baseball pitchers. *Ath Train Sport Health Care.* 2010;2(4):163-107.

155. Myers JB, Oyama S, Goerger BM, Rucinski TJ, Blackburn JT, Creigton RA. Influence of humeral torsion on interpretation of posterior shoulder tightness measures in overhead athletes. *Clin J Sport Med.* 2009;19(5):366-371.

156. Sabick MB, Kim YK, Torry MR, Keirns MA, Hawkins RJ. Biomechanics of the shoulder in youth baseball pitchers: implications for the development of proximal humeral epiphysiolysis and humeral retrotorsion. *Am J Sports Med.* Nov 2005;33(11):1716-1722.

157. Pieper HG. Humeral torsion in the throwing arm of handball players. *Am J Sports Med.* Mar-Apr 1998;26(2):247-253.

158. Whiteley R, Ginn K, Nicholson L, Adams R. Indirect ultrasound measurement of humeral torsion in adolescent baseball players and non-athletic adults: reliability and significance. *J Sci Med Sport.* Aug 2006;9(4):310-318.

159. Whiteley RJ, Ginn KA, Nicholson LL, Adams RD. Sports participation and humeral torsion. *J Orthop Sports Phys Ther.* Apr 2009;39(4):256-263.

160. Pink M. Understanding the Linkage System of the Upper Extremity. *Sports Med Arthrosc Rev.* 2001(9):52-60.

161. Edelson G, Teitz C. Internal impingement in the shoulder. *J Shoulder Elbow Surg.* Jul-Aug 2000;9(4):308-315.

162. Kluemper M, Uhl TL, Hazelrigg H. Effect of Stretching and Strengthening Shoulder Muscles on Forward Shoulder Posture in Competitive Swimmers. *Journal of Sport Rehabilitation.* 2006;15(1):58.

163. Page P. Muscle imbalances in older adults:improving posture and decreasing pain. *The Journal on Active Aging.* 2005.

164. Peterson DE, Blankenship KR, Robb JB, et al. Investigation of the validity and reliability of four objective techniques for measuring forward shoulder posture. *J Orthop Sports Phys Ther.* Jan 1997;25(1):34-42.

165. Borstad JD. Resting position variables at the shoulder: evidence to support a posture-impairment association. *Phys Ther.* Apr 2006;86(4):549-557.

166. Brossmann J, Preidler KW, Pedowitz RA, White LM, Trudell D, Resnick D. Shoulder impingement syndrome: influence of shoulder position on rotator cuff impingement--an anatomic study. *AJR Am J Roentgenol.* Dec 1996;167(6):1511-1515.

167. Kalra N, Seitz AL, Boardman ND, 3rd, Michener LA. Effect of posture on acromiohumeral distance with arm elevation in subjects with and without rotator cuff disease using ultrasonography. *J Orthop Sports Phys Ther.* Oct 2010;40(10):633-640.

168. Gumina S, Di Giorgio G, Postacchini F, Postacchini R. Subacromial space in adult patients with thoracic hyperkyphosis and in healthy volunteers. *La Chirurgia degli organi di movimento.* Feb 2008;91(2):93-96.

169. Lewis JS, Green A, Wright C. Subacromial impingement syndrome: the role of posture and muscle imbalance. *J Shoulder Elbow Surg.* Jul-Aug 2005;14(4):385-392.

170. Greenfield B, Catlin PA, Coats PW, Green E, McDonald JJ, North C. Posture in patients with shoulder overuse injuries and healthy individuals. *J Orthop Sports Phys Ther.* May 1995;21(5):287-295.

171. Soslowsky LJ, Thomopoulos S, Esmail A, et al. Rotator cuff tendinosis in an animal model: role of extrinsic and overuse factors. *Ann Biomed Eng.* Sep 2002;30(8):1057-1063.

172. Schneeberger AG, Nyffeler RW, Gerber C. Structural changes of the rotator cuff caused by experimental subacromial impingement in the rat. *J Shoulder Elbow Surg.* Jul-Aug 1998;7(4):375-380.

173. Virag B, Hibberd E, Oyama S, Padua D, Myers JB. Prevalence of Freestyle Biomechanical Errors in Elite Competitive Swimmers. *Sports health.* 2014;epub ahead of print.

174. Wymore L, Reeve R, Chaput C. No correlation between stroke specialty and rate of shoulder pain in NCAA men swimmers. *Int J Shoulder Surg.* 2012(6):71-75.

175. Troup JP. The physiology and biomechanics of competitive swimming. *Clin Sports Med.* Apr 1999;18(2):267-285.

176. Kennedy JC, Hawkins R, Krissoff WB. Orthopaedic manifestations of swimming. / Manifestations orthopediques de la natation. *American Journal of Sports Medicine.* 1978;6(6):309-322.

177. Prins J. The biomechanics of "unintended consequences": an examination of recent recommendations relating to swimming stroke mechanics. *American Swimming Magazine.* 2009(2):12.

178. Heinlein SA, Cosgarea AJ. Biomechanical Considerations in the Competitive Swimmer’s Shoulder. *Sports Health: A Multidisciplinary Approach.* November/December 2010 2010;2(6):519-525.

179. Andrews JR, Wilk KE, Reinold MM. *The Athlete's Shoulder*. 2 ed: A Churchhill Linvingstone Title; 2008.

180. Colwin CM. *Breakthrough Swimming*. Champaign, IL: Human Kinetics; 2002.

181. Wilk KE, Reinold MM, Andrews JR, eds. *The Athlete's Shoulder*. Philadephia: Churchill Livingstone; 2009.

182. McMaster WC, Troup J. A survey of interfering shoulder pain in United States competitive swimmers. *Am J Sports Med.* Jan-Feb 1993;21(1):67-70.

183. Rushall BS. Swimming Energy Training in the 21st Century: The Justification for Radical Changes. *Swimming Science Bulletin.* 2013;39:1-55.

184. Ebaugh DD, McClure PW, Karduna AR. Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics. *J Electromyogr Kinesiol.* Jun 2006;16(3):224-235.

185. Benjamin HJ, Briner WW, Jr. Little league elbow. *Clinical journal of sport medicine : official journal of the Canadian Academy of Sport Medicine.* Jan 2005;15(1):37-40.

186. Flynn MG, Pizza FX, Boone JB, Jr., Andres FF, Michaud TA, Rodriguez-Zayas JR. Indices of training stress during competitive running and swimming seasons. *Int J Sports Med.* Jan 1994;15(1):21-26.

187. MacKinnon LT. Special feature for the Olympics: effects of exercise on the immune system: overtraining effects on immunity and performance in athletes. *Immunology and cell biology.* Oct 2000;78(5):502-509.

188. Hackney AC, Koltun KJ. The immune system and overtraining in athletes: clinical implications. *Acta clinica Croatica.* Dec 2012;51(4):633-641.

189. Urwin M, Symmons D, al e. Estimating the burden of muscuolskeletal disorders in the community: The comparative prevalence of symptoms at different antatomical sites and the relation to social deprivation. *Ann Rheum Dis.* 1998;57(11):649-655

.

190. Bongers PM. The cost of shoulder pain at work. *BMJ.* 2001;322(7278):64-65.

191. Khamis HJ, Roche AF. Predicting adult stature without using skeletal age: the Khamis-Roche method. *Pediatrics.* Oct 1994;94(4 Pt 1):504-507.

192. Malina RM, Dompier TP, Powell JW, Barron MJ, Moore MT. Validation of a noninvasive maturity estimate relative to skeletal age in youth football players. *Clin J Sport Med.* Sep 2007;17(5):362-368.

193. Petersen AC, Crockett L, Richards M, Boxer A. A self-report measure of pubertal status: Reliability, validity, and initial norms. *Journal of youth and adolescence.* Apr 1988;17(2):117-133.

194. Brooks-Gunn J, Warren MP, Rosso J, Gargiulo J. Validity of self-report measures of girls' pubertal status. *Child development.* Jun 1987;58(3):829-841.

195. Shirtcliff EA, Dahl R, Pollak S. Pubertal Development: Correspondence between hormonal and physical development. *Child development.* 2009;80(2):327-337.

196. Dawson J, Fitzpatrick R, Carr A. A self-administered questionnaire for assessment of symptoms and function of the shoulder. *The Journal of bone and joint surgery. American volume.* May 1998;80(5):766-767.

197. Ekeberg OM, Bautz-Holter E, Tveita EK, Keller A, Juel NG, Brox JI. Agreement, reliability and validity in 3 shoulder questionnaires in patients with rotator cuff disease. *BMC musculoskeletal disorders.* 2008;9:68.

198. Roach KE, Budiman-Mak E, Songsiridej N, Lertratanakul Y. Development of a shoulder pain and disability index. *Arthritis care and research : the official journal of the Arthritis Health Professions Association.* Dec 1991;4(4):143-149.

199. Breckenridge JD, McAuley JH. Shoulder Pain and Disability Index (SPADI). *Journal of physiotherapy.* 2011;57(3):197.

200. Roy JS, MacDermid JC, Woodhouse LJ. Measuring shoulder function: a systematic review of four questionnaires. *Arthritis and rheumatism.* May 15 2009;61(5):623-632.

201. Leggin BG, Michener LA, Shaffer MA, Brenneman SK, Iannotti JP, Williams GR, Jr. The Penn shoulder score: reliability and validity. *J Orthop Sports Phys Ther.* Mar 2006;36(3):138-151.

202. Ellery T, Sauers E, Snyder A, Bay R. The design and development of the Functional Arm Scale for Throwers. *J Athl Train.* 2008;43(2, Suppl):S51.

203. Sauers E, Thigpen C, Huxel K, Bay R. Relationships Between Self-Reported Pain and Injury History, the Functional Arm Scale for Thorwers (FAST) and the Disabilities of the Arm, Shoulder, and Hand (DASH) in Adolescent Baseball Pichers. Paper presented at: American Society of Shoulder and Elbow Therapists 2009 Annual Meeting2009.

204. Norkin CC, White DJ. *Measurment of Joint Motion: A guide to Goniometry*. 2 ed. Philadelphia: F.A. Davis Company; 1995.

205. Myers JB, Oyama S, Wassinger CA, et al. Reliability, precision, accuracy, and validity of posterior shoulder tightness assessment in overhead athletes. *Am J Sports Med.* Nov 2007;35(11):1922-1930.

206. Thigpen C. Effects of forward head and rounded shoulder posture on scapular kinematics, muscle activity, and shoulder coordination. Chapel Hill: University of North Carolina at Chapel Hill; 2006.

207. Borstad JD. Measurement of pectoralis minor muscle length: validation and clinical application. *J Orthop Sports Phys Ther.* Apr 2008;38(4):169-174.

208. Borstad JD, Ludewig PM. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. *J Orthop Sports Phys Ther.* Apr 2005;35(4):227-238.

209. Michener LA, Subasi Yesilyaprak SS, Seitz AL, Timmons MK, Walsworth MK. Supraspinatus tendon and subacromial space parameters measured on ultrasonographic imaging in subacromial impingement syndrome. *Knee Surg Sports Traumatol Arthrosc.* Jun 5 2013.